SEA SURFACE AND RELATED SUBSURFACE TEMPERATURE ANOMALIES AT SEVERAL POSITIONS IN THE NORTHEAST PACIFIC OCEAN

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THESIS

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ABSTRACT

Sea surface temperature (SST) anomalies from previous sources have been related to subsurface temperature anomalies obtained from BT's at six positions in the Northeast Pacific. In this manner some understanding of the value of SST anomalies as indicators of ocean energy states is achieved. Results show that for about 50% of the time, the SST anomaly generally extended to depths of 100 meters or more. November through April were found to be the months most favorable for the occurrence of these deeply penetrating anomalies. Summertime SST anomalies were determined to be shallow features of less than 40 meters and were not indicative of subsurface heat content. A close linear relationship was observed year round between SST anomalies and heat content anomalies in the top 30 meters of the ocean. There was little correlation between SST and heat content anomalies in the 91-122 meter layer.

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I. INTRODUCTION

A. BACKGROUND

The connecting links in the ocean-atmosphere system are numerous and complex. On a large scale the system is analogous to a servomechanism wherein the ocean absorbs heat energy from the sun which is later fed back to the atmosphere to modify its wind patterns. The atmosphere in turn feeds energy back into the ocean to initiate another stage of the cycle.

On a smaller scale, storm systems may be generated or strengthened by interaction with the ocean. Numerous authors have attributed the development of cyclones over the ocean to the heat energy flux received from the sea [Pyke 1965]. Namias [1968] suggested that warmer than normal water lying in the path of migratory fronts and cyclones speeds up their cyclonic growth through the feedback of heat and moisture. Warm surface water conditions existed in the North Pacific during the summer-fall season of 1962 and could have been instrumental in causing the highly abnormal and adverse weather conditions in the Northern Hemisphere during the winter of 1962-63 [Namias 1963]. Annual precipitation patterns can be subtly affected by the heat distribution in the ocean and its year to year changes. Although significant correlation exists between energy feedback from the sea and weather patterns, Murray and Ratcliffe [1969] cautioned that the interactions are generally complex and that abnormal occurences cannot always be explained satisfactorily.

The majority of the heat energy available for transfer to the atmosphere is contained in the top 300 to 400 feet of the ocean. This is usually the greatest depth range to which seasonal changes in temperature are felt in the ocean for mid-latitude regions. An understanding of spatial and time variation of the thermal structure in the seasonal zone is required for an adequate explanation of ocean feedback effects on the atmosphere. Development of synoptic oceanographic analysis and weather forecasting requires quantitative knowledge of the amount of heat energy exchanged between the ocean and the atmosphere [Laevastu 1965].

Calculations of energy transfer across the air-sea interface are based on many parameters, one of which is the sea surface temperature [Wyrtki 1965]. Sea surface temperature is used in energy feedback computations because it is a critical parameter and is generally the only synoptic information available on the thermal conditions of the oceans. Isaacs [1969] has said that we need to know more than the surface temperature: "We need to know what is transpiring below the surface of the sea...so that we can determine such critical matters as the fluctuations in heat content...". Ideally, synoptic information on the subsurface temperature structure to the depth of seasonal influence should be used to provide heat content changes for feedback considerations, but the lack of sufficient observational coverage does not permit this as yet.

B. OBJECTIVE

Considerable emphasis to date in oceanographic and weather forecasting has been placed on sea surface temperature and sea surface temperature anomalies. The sea surface temperature anomaly is readily

available and can provide important information on the thermal energy content of the ocean. However, a large positive anomaly extending to 100 meters in depth represents a sizable amount of excess heat energy whereas the same anomaly existing to only 25 meters may not be as important in feedback considerations. Thus, knowledge of surface anomalies alone may not be sufficient to determine the potential effect of the ocean upon the atmosphere.

The object of this thesis is to study subsurface thermal structure anomalies to a depth of 122 meters (400 feet) and their relationship to the corresponding sea surface temperature (SST) anomalies at several locations in the Northeast Pacific Ocean from 1962-70. This will lead to a better appreciation for the reliability of SST anomalies as an indicator of the ocean energy levels. Such information might then be used to supplement the conclusions of Namias and others, that warmer than normal sea surface temperatures in the North Pacific provide an impetus for changes in the long-range weather patterns affecting the Northern Hemisphere.

C. SEA TEMPERATURES

To understand sea temperature anomalies at various depths, the factors affecting temperature structure through the layers involved must be considered. The factors that have the most effect on the surface and subsurface temperature structure may be divided into three groups (1) heat exchange, (2) mixing, and (3) advection [Wolff, et. al. 1965] . These three factors interact simultaneously in a non-linear manner to produce changes in the heat content and its distribution in the surface layer.

Changes in the thermal structure due to heat exchange across the air-sea interface result in near surface temperature gradients:

negative gradients for heat gained from or through the atmosphere and generally small positive gradient for heat loss to the atmosphere [LaFond 1954]. Heating at the surface is primarily caused by radiation from the sun and sky and produces negative temperature gradients, some of which may become large (Figure 1b). Conversely, removal of heat from the surface by: (1) back radiation from the sea surface, (2) sensible heat transfer to the atmosphere, and (3) evaporation, leads to positive gradients below the surface which usually remain small because of the associated convective mixing (Figure 1a).

Mixing and advection are described by LaFond [1962] as being the vertical and horizontal movements of water and the associated transfers of heat within the ocean which occur without loss or gain to the atmosphere. Local changes in the vertical and horizontal temperature gradients may result if the temperature of the advected water is different than that of the water it displaced.

Vertical mixing redistributes the heat in the ocean and is primarily responsible for determining the thermal structure with depth. There are two types of vertical mixing: (1) convective and (2) mechanical. Convective mixing will take place where a heat loss at the surface causes the cooled, denser water at the surface to sink.

Mechanical mixing is a forced mixing which may result from wave action produced by the wind. The primary effect of mechanical mixing is to produce a homogeneous layer with isothermal temperature structure. The higher the wind force, the greater the depth to which such mixing will take place (Figure 2).

Horizontal movement of water or advection will often result in the local temperature of the whole water column being changed in a similar

manner. A more complete discussion of all the factors that may affect sea temperatures is given by LaFond [1954, 1962] .

In discussing the thermal structure characteristics of the ocean (i.e., SST, mixed layer depth, ect.) the problem of defining the elements of "normal" structure arises. The normal thermal structure can be visualized as a climatic entity analogous to some in meteorology, dependent on time series data spanning a period of years; the larger the period the closer the approach to true climatological normals.

Once the mean thermal structure is known, it is possible to describe the ocean environment in terms of its variability around these mean values. In this case the variability can be depicted in terms of "persistence" and "anomalies".

Persistence is defined as the tendency of a disturbance in a fluid to continue for a period of time and then gradually die out. By knowing the persistence factor, it is possible to estimate when the environment will return to normal after a given time interval.

Anomalies are the departures of the observed state of the fluid in a given region over a specified time from the normal state for the same region and time. An anomaly is arrived at by subtracting the given temperature from the long term mean. Figure 3 shows the 30 day average SST analysis for January 1971 and Figure 4 is the SST anomaly analysis for the same month in 1971 when compared with the corresponding long term mean as computed by Fleet Numerical Weather Central (FNWC).

A variety of long term mean charts of SST have been generated over the years for the world's oceans and used for anomaly calculations. Wolff [1965] lists over twenty hydrographic and maritime climatologic

charts and atlases dating from 1898 to 1961 that are available for the Pacific Ocean. Some of the more recent publications of monthly mean SST for the Pacific were produced by Sette et. al. [1968] and LaViolette et. al. [1969] . Both Sette and LaViolette used bucket temperature and ship injection temperature reports for their analyses.

The Sette charts include means for each year in the period from 1949 to 1962. The SST data used to compute the monthly means were averaged over 2^{o} quadrangles of latitude and longitude. Investigators such as Isaacs [1969] , Namias [1968] , and Laevastu [personal communication] have used Sette's means in their computations.

LaViolette used over 6 million SST observations made between 1854 and 1960 in the North Pacific. The SST's were all averaged together by month in 1^{o} quandrangles. In addition to the charts of long term monthly means, LaViolette's work includes charts of monthly maximum and minimums of SST for the North Pacific.

Another source of monthly mean SST charts for the Northeast Pacific is the National Marine Fisheries Service (NMFS). This government organization within NOAA distributes charts of mean SST based on reported temperatures and computes SST anomalies from the long term mean. The primary use of this information is for the benefit of commercial fishermen in determining prime fishing areas. Typical NMFS sea surface temperature and anomaly charts are given in Figure 5.

A popular long term mean used by many, including Namias [1969] and NMFS, is given in an atlas published by the U. S. Naval Oceanographic Office [1944] . The atlas means are based on a 40 year period from about 1900 to 1940.

Some investigators have calculated their own norms using data from a particular period of interest. Clark [1967] found it useful to use a 7 year base (1951-1958) for his norm while studying SST fluctuations in the same period.

The mean SST values already discussed are based on bucket temperatures and merchant ship injection temperature reports. Robinson [unpublished] has compiled SST means for the North Pacific using all available bathythermograph (BT) and Nansen cast data since about 1946. FNWC is in the process of converting to the Robinson means in their anomaly computations [Laevastu, personal communication] .

Data to define long term mean temperature structure for the North Pacific is much less plentiful than data for SST norm values. Muromtsev [1963] gives the latitude-mean values of Pacific water temperatures at standard depths along longitude lines 10^{o} apart. Muromtsev based his calculations on 11,000 Nansen casts and 6,000 BT's. Panfilova [1968] produced similar charts, but used additional data and computed temperature values along longitude lines 1^{o} apart.

By far the most complete and probably the most reliable long term means of sea temperature in the vertical for the North Pacific are those compiled by Robinson. Her 20 year data base incorporates over 1.2 million BT's and Nansen casts. Temperature values were arrived at by averaging over 1^{o} quadrangles such that mean values are available for each whole degree of latitude and longitude for depths of 0, 100, 200, 300, and 400 feet.

II. APPROACH

A. GENERAL

Because temperature soundings are generally widely distributed in time and space and for practicality reasons, the study of SST and related subsurface temperature structure was limited to several positions in the Northeast Pacific. The main criteria for selecting a particular position for examination was the availability of data. Six locations were selected and are listed in Table I along with the inclusive dates covered by the data used.

These stations are located on a line between the California coast and Hawaii as shown in Figure 6. It can be seen that the stations lie along the well travelled shipping lanes that lead into San Francisco and Los Angeles, thus providing many opportunities for sea temperature reports in the vicinity of the selected points.

B. DATA SOURCES

Temperature data at the stations listed in Table I was obtained from several sources. Leipper [1954] summarized BT data taken by weather ships in the North Pacific from 1943 to 1952. Data for stations U, 4, and N were extracted from Leipper's report.

Scripps Institution of Oceanography was another source of data. They provided temperature measurements made from moored buoys on stations 16, 18, and 19. Evans, et. al. [1968] presents some of the temperature data collected in graphic and tabular form.

The largest portion of all BT data assembled for all stations was supplied by FNWC. It was not possible to obtain a sufficient density of

TABLE I

STATION POSITIONS AND DATES OF INCLUSIVE DATA USED

Station Designation	Position	Dates
16	33° 23' N 128° 38' W	10/62 - 3/70
18	32° 10' N 132° 47' W	10/62 - 3/70
19	30° 51' N 128° 37' W	10/62 - 3/70
N	30° 00' N 140° 00' W	7/46 - 6/50 1/65 - 2/70
4	33° 00' N 135° 00' W	7/50 - 6/52 10/62 - 3/70
U	28° 00' N 145° 00' W	7/50 - 6/52 10/62 - 3/70

BT's from FNWC by limiting the data to a 10 mile radius around each point, except for station N. Therefore, it was necessary to expand the area of interest and accept data within a 3° quadrangle centered upon each point. Approximately 4600 BT's were finally accumulated in this manner.

C. DATA PROCESSING

All data from Scripps and FNWC was received on 7-track magnetic tape. It was necessary to convert the information on the 7-track tape to a 9-track tape for use on the Naval Postgraduate School IBM 360 computer. Appendix A contains a sample computer program for accomplishing this purpose.

Initially the plan was to select one BT per day taken at the same time each day in order to minimize the diurnal effect and possibly that of internal waves. However, the lack of BT coverage at all stations but N precluded this. At station N, which is an Ocean Weather Station (OWS), only the 0600 G.M.T. BT was used. At all other stations, any BT that fell within the 3° quadrangle was used with no restrictions on the time of day it was taken.

For each station, all BT's in the same month and year were averaged to obtain the mean vertical temperature structure to a depth of 122 meters. The limitation imposed by using averaged temperature data in space and time are described by Holly [1968] . In this regard an assumption is made that the temperature soundings are evenly distributed throughout the month and the sample area such that the average is representative of the temperature structure at the point of interest. In some cases when only one sounding was available on the temperature structure for a particular month, it was used anyway and a note made.

The mean monthly BT's computed were used to calculate the heat content or heat excess in the water column for each month of the year.

Heat excess is defined as the difference in heat between the water sampled and a similar column of water at a temperature of 0° C. 0° C. is an arbitrary reference temperature and its choice was based only on previous usage [Pattullo, et. al. 1969] .

Heat content was computed using the formula

$$Q = \rho C_p T \Delta Z \times 10^{-3} \qquad (1)$$

where:

Q = heat content in layer ($kcal/cm^2$)

ρ = average density in layer (gm/cm^3)

C_p = specific heat at constant pressure of water in layer (cal gm^{-1} deg^{-1})

T = average temperature in layer ($^{\circ}C$)

ΔZ = thickness of layer (cm)

The temperatures used were picked off the mean monthly BT's at the standard depths, plus the even 100 foot depths to 400 feet (0,10,20,25, 30,50,61,75,91,100, and 122 meters). A linear temperature profile between depth points was assumed in computing the average temperature in each layer.

In computing Q from equation (1), the product of ρC_p is assumed to equal 1 cal cm^{-3} deg^{-1}. This appears to be a valid assumption in view of the fact that actual values of ρC_p computed by Pattullo [1969] from Nansen bottle data turned out to be .94 plus or minus a few percent.

Robinson's 20 year means for the vertical temperature profile were utilized in making the anomaly calculations of temperature and heat content for each month at intervals of 0, 30, 61, 91, and 122 meters.

The computer program used to compute the temperature means, anomalies, and heat content in the manner discussed above is given in Appendix A.

III. OCEANOGRAPHIC CLIMATOLOGY OF THE REGION

A. GENERAL

The oceanographic mechanisms involved in the formation of the surface layer in the North Pacific have been discussed in some detail by Tully [1964] . In order to familiarize the reader with the oceanographic properties of the ocean area under study, a few of the main topics in that paper are summarized below.

B. THE SUBTROPIC REGION

A region, as defined by Giovando [1965] , is an area of the ocean characterized by the unique distribution of one or more oceanographic properties in the horizontal and/or vertical direction. Figure 7 depicts the major surface circulation as found in the North Pacific, while Figure 8 shows its oceanographic Regions as defined by Tully [1964] . The area of interest is outlined by the rectangle and is seen to lie in the Subtropic Region.

The Subtropic Region is the largest of the oceanographic regions. In the eastern part of the Subtropic gyre the flow is southward and moves at relative slow speeds ($\sim$ 2 mi/day). This means that the surface waters will be continually changing their properties in adjusting to the local climate effects enroute.

In the Subtropic Region, evaporation exceeds precipitation year round. This results in evaporation-driven convection, where the denser water formed at the surface by evaporation sinks until it reaches an equilibrium level. Thus, a mixed layer can be formed that will exceed that produced by simple wind mixing. In the vertical, the salinity

distribution reaches a minimum between 200 and 800 meters and the density structure is largely a function of the temperature (Figure 9).

C. ANNUAL CYCLE OF TEMPERATURE STRUCTURE

The Subtropic Region undergoes a seasonal cycle of heating and cooling. The cycle features growth and decay of a seasonal thermocline which underlies a nearly isothermal surface layer (Figure 10). The seasonal thermocline develops and is maintained by the interaction of heating/cooling processes at the sea surface in addition to mechanical wind mixing. The depth to the top of the thermocline usually varies between 40 to 60 meters for this area. Depending upon the time of the year, the temperature at the bottom of the thermocline can be from 1^{o} to 8^{o} C less than that generally prevailing at the surface.

The season for net heating of the sea in the vicinity of station N (30^{o}N, 140^{o}W) usually is from mid-April to mid-September. Figure 11 is a plot of Robinson's long term mean temperatures for N and it shows the seasonal variation of temperature that occurs at different levels. The observed annual variation for all six stations using the monthly mean data are shown in Figures 12 to 18.

Cooling dominates the period from mid-September to mid-April. The seasonal thermocline is eroded away and sinks to about 150 meters; below this depth there is a permanent thermocline in the non-seasonal zone. The primary mixing agent during this period is convective overturn induced by surface cooling, although wind mixing is surely a factor in the near-surface layers. The surface layer will therefore become progressively thicker and will gradually become isothermal throughout.

IV. ANALYSIS OF RESULTS

A. GENERAL

Since all six stations lie within the same oceanographic region, the thermal structure at each was probably affected in similar ways by the surface processes during any given month. Therefore, in order to avoid being repetitious, only the thermal structure and changes thereto at station N will be described in a qualitative sense. Except for some general inferences, no attempt will be made to explain any heating or cooling observed in a quantitative manner. Such a study would be a topic for further research. Any unusual occurrences at the other stations will be discussed. In the end, all stations will be viewed collectively as a means of picturing the anomalous conditions that existed under the surface for this area of the North Pacific.

The results for each station are presented in two forms. First, Figures 19 through 46 show the mean monthly BT's for single years as computed from the data, along with the corresponding Robinson long-term monthly mean temperature structure. Thus, one can see at a glance the anomalously warm (shaded portions) or cold water layers.

The second series of plots, Figures 47 to 56, depict the anomalies that existed at various depths versus time in months. This presentation allows the reader to observe the persistence of various anomalies in addition to the times and depths of positive or negative anomalies.

B. STATION N (1965-69)

It is readily apparent from Figure 48 that the temperature anomaly at the surface in many cases is not of the same sign (i.e., positive or

negative) throughout the layer. The same figure also compares three SST anomalies and shows that there is disagreement among them. The Sette and NMFS anomalies depended upon ship injection temperature reports which are subject to various errors [Saur 1963]. Likewise the averages taken from BT's lead to other difficulties. In addition, differences could also result from the smoothing techniques used. Such a comparison points up the variability that can occur in anomalies depending on what long term mean was used.

Referring to Figures 23, 24, and 25, it can be seen that in January 1965 the surface mixed layer is warmer than normal to 75 meters but has colder than normal water below the thermocline. By March, mixing processes have distributed the heat in the upper layer throughout the column, bringing about isothermal and warmer than normal water conditions. Apparent cooling at the surface probably resulted in convective overturn through April 1965 and introduced below normal temperatures in the layer. It is possible that advection of cooler than normal water into the region maintained the below normal structure through June. Note how the SST anomaly from March through August 1965 is representative of the whole column. Cooling at the surface commenced in September introduces convective mixing, thus deepening the mixed layer. The surface cooling was apparently fairly rapid because of the negative anomaly that developed in the mixed layer from October to December. Below the thermocline, a region of warmer than normal water is seen to exist.

By January 1966 the whole layer has become isothermal, but slightly cooler than normal. The fall of 1966 was nearly "normal" except for the month of September which experienced less than normal warming at the surface, resulting in a negative anomaly in the mixed layer. In October,

the water above the thermocline warmed up either through insolation or advection of warm water, while conditions below the thermocline remained nearly constant. Cooling did not start until December and continued through February 1967. Slightly cooler than normal water was initiated and these conditions lasted until July 1967. In August 1967 a warm pool of water is seen in the surface layers, possibly brought about by strong heating under calm conditions. Figure 24 shows that a sharp negative thermocline has formed, presenting an extremely stable condition that inhibits the flow of heat downwards [Dietrich 1963, page 174]. Thus a situation occurred where the surface temperature indicated anomalously warm water but at depths below the thermocline (25-50 meters), colder than normal water existed. Again in the late fall, cooling at the surface takes place, leading to convective overturn and this combined with probable mechanical wind mixing, deepens the isothermal mixed layer. The warmer than normal conditions of 1967 plus possible advection of warm water has helped to retard the normal rate at which the water is usually cooled, resulting in warmer than normal conditions for January-February 1968. By March, the water has returned to a near normal state and remains so through May 1968. Commencing in June 1968 a sharp thermocline appears at about 40 meters, once more indicating strong heating at the surface. Here again a very warm upper layer develops and the heat is contained in the near surface layers by the presence of the thermocline. Since in the spring of 1968 the water column was near normal or slightly warmer than normal, the deeper layers (below 50 m.) were near normal from June through September 1968. The usual cooling processes leading to mixing take over in October to erode away the thermocline. Overall in 1968, station N was characterized by warmer than normal water above 50 meters.

January of 1969 was very much warmer than normal as a result of a very warm year in 1968. Cold water possibly moved into the region beginning in February and brought temperatures down to below normal. A warming trend set in from May through July 1969. Apparently very little surface heating occurred from August to October and this led to below normal conditions. Advection of warm water could have been responsible for warming the surface layers in the fall of 1969.

In summary then, it has been indicated that at station N anomalous cooling or heating in the spring is primarily accomplished through advection since the whole water column is affected in the same manner. Support for this is evidenced in a study by Bathen [1971] , who calculated that on the average, advection is responsible for 63% of the local monthly change in heat storage for most of the North Pacific.

If strong heating occurs during the summer months, the SST anomaly does not appear to be a true indicator of the thermal structure in the whole water column. The development of a strong thermocline leads to very stable water conditions, preventing the transport of heat downward. The water temperatures below the thermocline will depend on what thermal conditions existed prior to the onset of the rapid surface heating. The fall months are charcterized by "a leveling out" of the thermal structure and a general cooling of the column through convective overturn and mixing processes.

C. STATION N (1946-50)

Vertical temperature structure for station N from 1946 to 1950 is shown in Figures 44 and 45. Data for these BT's was extracted from the report by Leipper [1954] who compiled temperatures for these years at

depths of 0, 100, 200, and 350 feet. As a result, the temperature structure shown in the BT profiles may not be the true structure since there was linear interpolation for the intermediate temperature values. However, valid anomalies do exist at 0, 30, 61, 91, and 106 meters which correspond to the depths used by Leipper.

It is evident from Figures 44 and 45, that similar processes affected the temperature structure at station N during 1946-50 as have been described for 1965-69.

D. OTHER STATIONS

In general, observations were not as numerous at stations 4, 16, 18, 19, and U as they were at N and therefore the computed means may not truly represent the average conditions of the month. It can be seen from the comparison of the SST anomalies at each station (Figures 47 to 56) that the general trends of the Robinson anomaly agrees with the Sette and NMFS anomalies, but that there are greater differences between these than there are at station N.

Two years where no data were available from station N, 1963 and 1964, are available for study at these other stations. The principal features prevailing at many stations during the summer of 1963 was the fact that the surface layers were cooler than normal for these months. The year 1964 had a very similar occurrence during the summer with negative anomalies from the surface to depths varying from 25-75 meters. In most cases there was warmer than normal water at greater depths.

A feature of some interest in the thermal structure is the appearance of a sub-thermocline duct which is related to subsurface anomalies. The ducts appeared primarily in the summertime at the more northerly stations (4, 16, 18, 19). Sub-thermocline ducts were very prominent at

station 16 from May through August 1964 (Figure 35), with an indication that they were also present at stations 18 and 19 for the same period (Figures 30 and 40). This is in agreement with Burrows' [1968] observations which showed that although the ducts are characteristic of the Subarctic Region (See Figure 8), small ducts do occur during the summer months for this area.

E. COMPOSITE VIEW OF STRUCTURE

In order to tie together the observations made of the average subsurface temperature structure at different locations, it is interesting to look at the surface anomaly chart for the Northeast Pacific that existed at the same time.

1. October 1963. Figure 57 shows that all of the stations lie in a positive surface anomaly area. The BT plots associated with this month all have positive anomalies at the surface. All have very small or positive anomalies existing over the whole depth of the water column. Stations 16 and 19 lie in or are adjacent to the relatively large positive surface anomaly area on the chart and appear to maintain a constant anomaly with depth.
2. May 1964. In Figure 58 all stations lie in a negative anomaly region except for 19. From the BT's it is seen that the negative anomaly exists to only very shallow depths, with generally warmer than normal water below 50 meters. A discrepancy at station 19 exists between the chart and the BT anomaly at the surface. The BT structure is probably more correct based on the fact that its thermal structure is in general agreement with the other stations nearby and because it is a moored buoy station with hourly recorded temperatures.

3. June 1965. From the SST anomaly chart in Figure 59, one sees that station U and N lie in a positive anomaly area, station 4 is on the dividing line between negative and positive anomalies, and that stations 16, 18, and 19 all have negative SST anomalies. In the BT plot, stations 16 and 18 show very shallow negative anomaly layers near the surface and warmer than normal water below 25 meters. For station 19, the negative anomaly exists to 90 meters before changing to a positive anomaly. station U shows that it is warmer than normal from the surface to 122 meters. The average BT at station N reveals a slightly negative anomaly at the surface which is contrary to the SST anomaly chart. It does not appear to be consistent with the other stations.

4. April 1967. The surface chart in Figure 60 places all stations in the negative anomaly region except for U which is on the fringe of a positive anomaly area. The subsurface structure discloses the fact that the negative anomaly at the surface is generally found to exist to 100 meters except for station 16.

5. September 1967. A positive SST anomaly now occupies most of the Northeast Pacific as shown in Figure 61. The average thermal structure below the surface in this area of positive surface anomalies reveals a shallow, warmer than normal mixed layer about 25 meters deep, a sharp thermocline, and generally cooler than normal water below the thermocline. The structure at station 16 is based on only one BT and may not portray the true average structure.

6. July 1968. Another large positive SST anomaly formed in 1968. Figure 62 depicts the associated subsurface thermal structure

that also occurred. The shallow, warm, mixed layer is again in evidence.

7. February 1969. All of the stations shown in Figure 63 are situated in a positive anomaly locale. The related BT's for the month indicate that the warmer than normal water which formed at the surface in 1968 has now been mixed vertically to produce a warmer than normal column of water to a depth of 122 meters.

F. VERTICAL SECTIONS

Local temperature anomalies can be thought of as a displacement of isotherms from their normal positions because of advection. Vertical temperature sections comparing the observed temperature values with the norm would reveal the amount of lateral displacement that occurred. Two contrasting vertical sections representing the coolest and warmest months are shown in Figures 64 and 65. Section A-A' is taken through stations U, N, 18, and 16, while section B-B' is through stations 4, 18, and 19. Section A-A' is aligned so that the general surface drift is nearly perpendicular to it.

Section A-A' and B-B' made in February (representing the coolest month) 1969 and depicted in Figure 64 shows that there was a possible shift in the isotherms to the northeast of about 120 miles.

For September 1969, Figure 65, indicates that above 50 meters the shift in isotherms was to the southwest, while below 50 meters there may have been a slight shift to the northeast. The displacement of isotherms above 50 meters also seemed to increase as one went westward from station 16.

G. SUMMARY

The above composite views suggest that for this region, an anomaly at the surface (without regard as to the sign) exists to depths of 100 meters or more during the late fall and early spring months. The depths of penetration for all observed surface anomalies versus the percentage of the total observations are plotted in Figure 66. This graph shows a small peak for negative anomalies at 20-40 meters and large peak at 100-120 meters. The positive anomalies have a broad peak between 40-80 meters in addition to a sharp peak at 100-120 meters. These results indicate that for about 50% of the time the anomaly at the surface exists throughout the water column. This outcome called for further investigation of the anomalies extending throughout the surface layers. Figure 67 is a breakdown of the magnitudes of the surface anomalies that existed at times when the anomalies also penetrated to at least 100 meters. There is a hint, from Figure 67, that the magnitude of the positive anomaly was generally less than 1.0^{o}C while the negative anomaly was usually greater than 1.0^{o}C. In addition, more negative than positive anomalies were observed to extend from the surface to 100 meters. This might well be expected because convective mixing processes would tend to deepen negative anomalies that appear at the surface. The number of anomalies whose magnitudes were greater than 1.6^{o}C is not considered sufficient to indicate any valid conclusions. The distribution by month of occurrence for surface anomalies that penetrated to 100 meters is shown in Figure 68. The preferred months for the positive anomalies were January and February, while the negative anomalies favored March and April. The positive anomalies during the winter possibly can be explained through persistence mechanisms. The warm

anomaly forms at the surface during the summer and if it is large enough it will persist into the winter gradually becoming deeper with the increasing depth of the mixed layer.

Figure 21 for station U (1968-1969) is an example of how the positive anomaly develops at the surface during the summer and eventually works its way down to the bottom of the layer by February of the following year.

Negative anomalies penetrating from the surface to 100 meters can be expected for the months of February, March, and April, because these are generally the coolest months of the year for this region. Once cooling at the surface has introduced a negative anomaly, convective mixing will bring about a net cooling of the deeper layers. If cooling at the surface continues, then a deep negative temperature anomaly will result.

Graphs showing the distribution of magnitude and month of occurrence for surface anomalies that existed to 40 meters are given in Figures 69 and 70. Figure 69 shows a sharp cut-off in the number of surface anomalies whose magnitudes are larger than 1.5°C, whereas anomalies that extend to 100 meters have a cut-off at values greater than 2.0°C. (Figure 67).

Negative anomalies to 40 meters were most common during the month of August as depicted in Figure 70. A possible explanation for this is that during the summer season positive anomalies are usually shallow features that can be easily wiped out by cooling at the surface and result in negative anomalies.

Figure 70 shows that positive anomalies existing to 40 meters occurred primarily during July and November. The high number of occurrences in

November is the result of a deepening of the mixed layer during the fall months of the year. It was previously noted that positive anomalies to 100 meters favored the months of January and February, therefore anomalies to some intermediate depth between 40 and 100 meters must be prevalent during December.

V. CORRELATION STUDIES

The relationship between the SST anomaly and the heat content anomaly in layers of various thicknesses was evaluated first on an annual and then on a seasonal basis. The year was divided into three seasons for the seasonal correlation study. The choice of seasons was based upon the seasonal variation of temperature displayed in the upper 122 meters (see Figure 11).

The average linear correlation coefficients obtained for all six stations is given in Table II. The coefficients in Table II indicate that there is an almost linear relationship between the SST and heat content anomalies in the top 30 meters for this particular area of the North Pacific. There is a decrease in correlation values as the layer thickness increases. The seasonal coefficients for the heating season are lower than those for other times of the year. This is evidence that, in general, only shallow mixed layers (less than 30 m) are formed from May to August. Very little linear correlation exists between the SST and heat content anomalies in the bottom most layer of 91-122 meters. Some typical correlation plots for station N, Figures 71 to 75, portray some of the observations made above.

An attempt was made to improve the correlation coefficients between SST and heat content anomalies in the layers of 30-61, 61-91, and 91-122 meters by applying lags of 1, 2, or 3 months. For the 30-61 meter layer, there was no improvement in the coefficients for lags from 1 to 3 months, indicating possible relationships of less than one month's

lag. Correlations with applied lags in the other two layers were not very conclusive, however, the best correlations were obtained with 3 months lag.

TABLE II

CORRELATION COEFFICIENTS BETWEEN SST ANOMALY AND THE HEAT CONTENT ANOMALY IN THE LAYER

a. Annual

	Depth Interval (m)						
	0-30	0-61	0-91	0-122	30-61	61-91	91-122
Correlation Coeff.	.98	.91	.84	.79	.77	.63	.54

b. Seasonal

	Depth Interval (m)						
Season	0-30	0-61	0-91	0-122	30-61	61-91	91-122
Jan-Apr	.99	.98	.95	.91	.96	.85	.67
May-Aug	.94	.83	.76	.71	.63	.55	.54
Sep-Dec	.99	.92	.81	.71	.73	.44	.34

VI. CONCLUSIONS

This study was involved with the description of subsurface temperature anomalies and the associated SST anomalies for a restricted area of the Subtropical Northeast Pacific.

The results of this research show that:

1. Positive SST anomalies that formed during the heating season generally penetrated to less than 30 meters. This may be related to the action of a stronger seasonal thermocline in preventing transfer of heat downward.
2. Negative SST anomalies that occurred in the heating season usually existed only in shallow depths (10-20 m).
3. SST anomalies observed during the months of December through April were usually indicative of thermal conditions to at least 80-100 meters.
   a) About 50% of all the positive SST anomalies observed extended to 100 meters. The majority of these "deep" anomalies were found to occur in the months of December, January, and February. It is suggested that once a large positive SST anomaly is established in the early fall months, the mixing processes help to distribute the excess heat vertically to at least 100 meters to form a warmer than normal mixed layer. This anomalously positive layer then may persist through February.
   b) The majority of the negative SST anomalies observed that existed throughout the surface layer, occurred during the months of March and April. Since these are the coolest months

of the year for this region, any negative anomaly formed at the surface would soon be felt to 100-120 meters through the action of convective mixing.

4. A very close linear relationship between SST anomaly and heat content anomaly was observed year round for the top 30 meters of the ocean.
5. The linear correlation coefficient decreased as the layer thickness from the surface increased.
6. The seasonal correlation between SST anomaly and heat content anomaly was always the lowest during the heating season (May-August). Significant drop off in the coefficient value occurred in this season if the layer thickness increased beyond the 0-30 meter level.
7. Little linear correlation was observed between the SST and the heat content anomalies in the 91-122 meter layer. There was some indication that the correlation could be improved for this layer if a 3 month lag time was applied. Non-linear relationships between the SST and heat content anomalies below 100 meters may exist because of possible non-seasonal fluctuations in heat content.

VII. RECOMMENDATIONS

Recent studies suggest that the North Pacific is a highly influential factor in controlling the development of this nation's winter weather patterns. A greater understanding of the air-sea interation relationships in this ocean area could aid in developing more reliable long-range weather predictions.

It is recommended that a study of the type just completed, be conducted over a larger area of the Northeast Pacific with a reasonable grid network superimposed for sampling points. An interesting period that might be considered for observation is from 1967 through 1970. This four year period includes contrasting sea surface temperature anomalies in the Northeast Pacific as well as contrasting weather types on the east and west coasts of the U. S. that might be related.

There are numerous avenues available for research in this type of study once the subsurface thermal structure has been reconstructed. Some of the research possibilities are:

1) Develop the heat budget for the region; determining the quantity of heat advected into and out of the region in addition to the heat exchange across the air-sea interface on a monthly, seasonal, and yearly basis.
2) Attempt to relate the heat exchange values to any major storm systems that may have crossed the region to see if the heat flux from the ocean could have played an important role in intensifying them.

3) Test presently developed empirical relationships between the atmosphere, sea surface, and subsurface parameters to check their validity and areas for possible improvement.

In the end, perhaps a better comprehension of how the North Pacific Ocean affects this continent's weather will result.

APPENDIX A

Computer Programs

7-TRACK TO 9-TRACK TAPE CONVERSION PROGRAM

THIS PROGRAM WILL CONVERT DATA WRITTEN ON THREE 7-TRACK MAGNETIC TAPES ONTO ONE 9-TRACK TAPE. THE FIRST RECORD ON THE 9-TRACK TAPE IS PRINTED OUT AS A CHECK THAT THE CONVERSION WAS CARRIED OUT PROPERLY.

FOR FURTHER INFORMATION ON MAGNETIC TAPE CONVERSION AND PROCESSING AT THE NAVAL POSTGRADUATE SCHOOL SEE:

> RANEY, S.D., "PROCEDURE FOR CONVERTING 7-TRACK MAGNETIC TAPE TO 9-TRACK MAGNETIC TAPE", NPGS TECH. NOTE NO. 0211-08, JUNE, 1970.

```
//NAME, ECT.      JOB CARD
//CCNVERT  EXEC   FORTCLG,TIME.GO=12
      DIMENSION INDATA(30)
      REWIND 4
      J=0
      NT=2
   32 REWIND NT
   31 J=J+1
  200 READ(NT,3,END=40,ERR=50) INDATA
    3 FORMAT(30A4)
   90 WRITE(4,3) INDATA
      GO TO 31
   50 WRITE(6,51) J
   51 FORMAT('0',5X,'READ ERROR, RECORD NO. =',I8)
      GO TO 31
   40 WRITE(6,44) J
   44 FORMAT('0',5X,'END OF TAPE, RECORD NO. =',I8)
      END FILE 4
      REWIND 4
      DO 100 K=1,2
      READ(4,3) INDATA
      WRITE(6,3) (INDATA(I), I=1,30)
  1CO CCNTINUE
      STOP
      END
//GO.FT02F001   DD   UNIT=2400-1,VOLUME=SER=(BELA1,BELA2,
//          BELA3),LABEL=(,NL),DISP=OLD,DCB=(DEN=1,RECFM=F,
//          BLKSIZE=120,TRTCH=ET)
//GO.FTC4F001   DD   UNIT=2400,VOL=SER=NPS261,LABEL=(,SL),
//          DSNAME=BELAND,DISP=(NEW,KEEP),DCB=(DEN=2,
//          RECFM=FB,LRECL=120,BLKSIZE=120)
```

TAPE EXTRACT PROGRAM

THIS PROGRAM WILL EXTRACT UP TO 350 BT'S FROM 9-TRACK MAGNETIC TAPE AND PUNCH OUT THE TEMPERATURE VALUES ON CARDS WITH DATE,LATITUDE, LONGITUDE,AND TIME. BT AND NANSEN CAST DATA ON THE TAPE IS WRITTEN IN THE STANDARD FNWC FORMAT AND CONTAINS TWO FILES OF DATA. IF ADDITIONAL BT'S ARE ON THE TAPE AND HAVE NOT BEEN SEARCHED BECAUSE THE MAXIMUM LIMIT OF 350 HAS BEEN REACHED, THEN RERUN THE PROGRAM INSERTING THE PROPER IF STATEMENT AS SHOWN BELOW IN THE PROGRAM

DEFINITION OF PARAMETERS USED

INDATA = LAT,LONG,DATE,TIME
ISST = BT SEA SURFACE TEMP IN DEG F
ID,IT = BT DEPTHS IN FEET AND BT TEMP IN DEG F AS READ OFF TAPE
D,T = CONVERTED DEPTH TO METERS AND TEMP TO DEG C
Z = STANDARD DEPTHS(11) FOR WHICH DATA WILL BE LINEARLY INTERPOLATED FOR
KK1,KK2,KK3,KK4 = LATITUDE AND LONGITUDE COORDINATES OF AREA TO BE SEARCHED. FOR EXAMPLE, 31 DEG 00'N IS WRITTEN AS 3100 WHILE 127 DEG 00'W BECOMES 1270
ITAG3 = MONTH AND YEAR FOR SEARCH TO BEGIN ON RERUN AFTER MAX OF 350 BT'S WAS REACHED ON FIRST RUN.
TEMP = INTERPOLATED TEMPERATURE VALUES IN DEG C.

```
//NAME   (JOB CARD)
//PROCESS   EXEC   FORTCLGP,REGION.GO=200K,TIME.GO=3
//FORT.SYSIN   DD *
      DIMENSION INDATA(6,350),ISST(350),ID(24,350),
     $IT(24,350),D(24,350),T(24,350),SST(350),Z(11),
     $DUMMY(80)
      COMMON TEMP(11,350)
      DATA ITAG1/'A   '/,ITAG2/'C   '/,KK1/'3100'/,
     $KK2/'3500'/,KK3/'1270'/,KK4/'1300'/,ITAG3/'0968'/
```

DEPTHS IN METERS AT WHICH TEMPERATURES WILL BE INTERPOLATED FOR

```
      DATA Z/0.0,10.0,20.0,25.0,30.0,50.0,61.0,75.0,91.0,
     $100.0,122.0/
      J=0
      N=0
      NR=1
      NK=1
      REWIND 4
  100 IF(J.EQ.351) GO TO 551
      CALL REREAD
      READ(4,500,END=551) IDENT,IDATE,LAT,LONG,ITIME
  500 FORMAT(8X,A1,2X,A4,2X,A4,1X,A4,2X,A4)
      IF(IDENT.EQ.ITAG1) GO TO 101
      IF(IDENT.EQ.ITAG2) GO TO 101
      IF(LAT.LT.KK1) GO TO 101
      IF(LAT.GT.KK2) GO TO 101
      IF(LONG.LT.KK3) GO TO 101
      IF(LONG.GT.KK4) GO TO 101
```

BT'S ARE IN CHRONOLOGICAL ORDER ON TAPE. THEREFORE, IF SECOND RUN IS NEEDED TO COMPLETE SEARCH, SIMPLY INSERT THE FOLLOWING IF STATEMENT WITH MONTH AND YEAR OF LAST BT EXTRACTED FROM PRIOR RUN.

```
*****IF(IDATE.LT.ITAG3) GO TO 101*******

  102 J=J+1
      READ(99,10) (INDATA(I,J), I=1,6), ISST(J),
     $(ID(I,J),IT(I,J), I=1,6)
   10 FORMAT(9X,I6,2X,2I2,1X,I2,I3,1X,I4,9X,I3,6(1X,I2,I3))
      IF(J.EQ.1) GO TO 20
      IF(INDATA(6,J).NE.INDATA(6,J-1)) GO TO 20
```

```
      IF(INDATA(1,J).NE.INDATA(1,J-1)) GO TO 20
      NR=NR+1
      NK=NK+1
      IF(NK.GE.5) GO TO 100
      GO TO 21
   20 N=N+1
      ISST(N)=ISST(J)
      DO 11 I=1,6
      INDATA(I,N)=INDATA(I,J)
      ID(I,N)=ID(I,J)
      IT(I,N)=IT(I,J)
   11 CONTINUE
      GO TO 90
   21 IF(NR.EQ.3) GO TO 13
      IF(NR.EQ.4) GO TO 15
      K=7
      DO 12 I=1,6
      ID(K,N)=ID(I,J)
      IT(K,N)=IT(I,J)
      K=K+1
   12 CONTINUE
      GO TO 100
   13 K=13
      DO 14 I=1,6
      ID(K,N)=ID(I,J)
      IT(K,N)=IT(I,J)
      K=K+1
   14 CONTINUE
      GO TO 100
   15 K=19
      DO 16 I=1,6
      ID(K,N)=ID(I,J)
      IT(K,N)=IT(I,J)
      K=K+1
   16 CONTINUE
      GO TO 100
  101 READ(99,550) DUMMY
  550 FORMAT(80A1)
      GO TO 100
   90 NK=1
      NR=1
      GO TO 100
C
      THIS LOOP CONVERTS FEET TO METERS AND DEG F TO DEG C.
C
  551 DO 30 J=1,N
      DO 31 I=1,24
      D(I,J)=3.048*ID(I,J)
      T(I,J)=(5.0/9.0)*((0.1*IT(I,J))-32.0)
   31 CONTINUE
      SST(J)=(5.0/9.0)*((0.1*ISST(J))-32.0)
   30 CONTINUE
      CALL TINPOL(D,Z,T,SST,N)
      WRITE(6,70) ((TEMP(I,J), I=1,11),(INDATA(I,J), I=1,6),
     $J=1,N)
      WRITE(7,71) ((TEMP(I,J), I=1,11), (INDATA(I,J), I=1,6)
     $, J=1,N)
   70 FORMAT(1X,11F5.1,1X,I6,3X,2I2,1X,I2,I3,1X,I4)
   71 FORMAT(11F5.1,1X,I6,3X,2I2,1X,I2,I3,1X,I4)
      STOP
      END
THIS SUBROUTINE TAKES 'NR' BT'S AND INTERPOLATES FOR TEMPS
AT THE STANDARD DEPTHS.


      SUBROUTINE TINPOL(DEP,ZZ,TT,SST,NR)
      DIMENSION DEP(24,NR),ZZ(11),TT(24,NR),SST(NR)
      COMMON TEMP(11,350)
      DO 10 J=1,NR
      L=1
      DO 20 I=1,11
```

```
      IF(I.EQ.1) GO TO 21
   40 IF(DEP(L,J)-ZZ(I)) 30,31,32
   30 L=L+1
      IF(L.EQ.25) GO TO 10
      GO TO 40
   32 IF(L.EQ.1) GO TO 33
      DIFF=DEP(L,J)-DEP(L-1,J)
      DIFF1=ZZ(I)-DEP(L-1,J)
      PER=DIFF1/DIFF
      DIFFT=TT(L,J)-TT(L-1,J)
      FACT=PER*DIFFT
      TEMP(I,J)=TT(L-1,J)+FACT
      GO TO 20
   21 TEMP(I,J)=SST(J)
      GO TO 20
   33 PER=ZZ(I)/DEP(L,J)
      DIFFT=TT(L,J)-SST(J)
      FACT=PER*DIFFT
      TEMP(I,J)=SST(J)+FACT
      GO TO 20
   31 TEMP(I,J)=TT(L,J)
      GO TO 20
   20 CONTINUE
   10 CONTINUE
      RETURN
      END
THE FOLLOWING JCL CARDS IDENTIFY THE TAPE BEING SEARCHED
AS SERIAL NO. NPS261.  THE FILE NUMBER 1 IS INDICATED IN
THE LABEL PARAMETER AS (,SL); FILE NO. 2 WOULD BE CODED AS
(2,SL).
//GO.FT04F001  DD  UNIT=2400,VOL=SER=NPS261,LABEL=(,SL),
//        DSNAME=BELAND,DISP=OLD,DCB=(DEN=2,RECFM=FB,
//        LRECL=120,BLKSIZE=120
//GO.SYSIN  DD *
```

HEAT CONTENT PROGRAM

THIS PROGRAM WILL TAKE 3 YEARS WORTH OF BT'S AND COMPUTE THE MONTHLY MEAN BT'S FOR EACH YEAR TO A DEPTH OF 122 METERS. THESE MEANS ARE COMPARED AGAINST A LONG TERM MEAN IN ORDER TO COMPUTE TEMPERATURE AND HEAT ANOMALIES TO 122 METERS IN DEPTH.

BT'S WILL BE ARRANGED IN CHRONOLOGICAL ORDER BY THE PROGRAM AND NEED ONLY BE GROUPED BY YEAR IN THE DATA DECK.

DEFINITION OF PARAMETERS USED

N,M,K=NO. OF BT'S IN EACH YEAR
TNORM=12 MONTHLY LONG TERM MEANS FOR DEPTHS OF 0,30,61,91,AND 122 METERS
T1,T2,T3=BT TEMPERATURE VALUES FOR 3 YEARS IN DEG C. AT DEPTHS OF 0,10,20,25,30,
50,61,75,91,100,AND 122 METERS

```
//NAME   JOB   ETC.
//     EXEC  FORTCLGP,REGION.GO=150K,TIME=3
//FORT.SYSIN  DD *
C        BASE=REFERENCE TEMPERATURE FOR HEAT CALCULATIONS IN DEGREES C.
C          THE DEPTH INCREMENTS ARE (0,10,20,25,30,50,61,75,91,
C          100, AND 122 METERS)
      DIMENSION T1(11,250),DAY1(250),MO1(250),IYR1(250),T2(11,250),
     $DAY2(250),MO2(250),IYR2(250),T3(11,250),DAY3(250),MO3(250),
     $IYR3(250),TAVE(11,12),DEPTH(11),DNORM(5),TNORM(11,12),QN(4,12)
      DIMENSION KOUNT(12),QA(4,12),SA(4,12),TAN(5,12),XMO(12),SN30(12),
     $SN61(12),SN91(12),SN122(12)
      COMMON Q(10,250),QZ(10,250),SUM30(12),SUM61(12),SUM91(12),
     $SUM122(12),DIFF61(12),DIFF91(12),DIF122(12),TITLE(12),
     $ID1(4),ID2(4),IPOS(3)
      INTEGER DAY1,DAY2,DAY3
      DATA DNORM/0.0,30.0,61.0,91.0,122.0/,TNORM/132*0.0/
      DATA XMO/-0.5,-1.5,-2.5,-3.5,-4.5,-5.5,-6.5,-7.5,-8.5,-9.5,-10.5,
     $-11.5/
      CATA T1/2750*0.0/,T2/2750*0.0/
      REAL LABL1/4H SST/,LABL2/4HHEAT/,LABL3/4H    /
      REAL*8 ITITL1(12),ITITL2(12)
      REAL*8 ID1,ID2
      REAL*8 TITL2(6)
      N=28
      M=52
      K=57
      IYEAR1=1946
      IYEAR2=1947
      IYEAR3=1948
      READ(5,12) ((TNORM(I,J), I=1,5), J=1,12)
   12 FORMAT(5F5.1)
```

```
      READ(5,13) TITLE
   13 FORMAT(12A3)
      READ(5,10) ((T1(I,J),  I=1,11),DAY1(J),MO1(J),IYR1(J),  J=1,N)
      READ(5,10) ((T2(I,J),  I=1,11),DAY2(J),MO2(J),IYR2(J),  J=1,M)
      READ(5,10) ((T3(I,J),  I=1,11),DAY3(J),MO3(J),IYR3(J),  J=1,K)
   10 FORMAT(11F5.1,1X,2I2,I4)
      READ(5,11) DEPTH
   11 FORMAT(11F5.1)
      READ(5,40) (ID1(I), I=1,4)
      READ(5,40) (ID2(I), I=1,4)
   40 FORMAT(4A8)
      READ(5,1) (TITL2(I), I=1,6)
    1 FORMAT(6A8)
      READ(5,201) (IPOS(I), I=1,3)
  201 FORMAT(3A4)
C
C        SORTING BT'S BY DAY AND MONTH
C
      CALL SORT(MO1,DAY1,IYR1,T1,N)
      CALL SORT2(DAY1,MO1,IYR1,T1,N)
      CALL SORT(MO2,DAY2,IYR2,T2,M)
      CALL SORT2(DAY2,MO2,IYR2,T2,M)
      CALL SORT(MO3,DAY3,IYR3,T3,K)
      CALL SORT2(DAY3,MO3,IYR3,T3,K)
      WRITE(6,10) ((T1(I,J),  I=1,11),DAY1(J),MO1(J),IYR1(J),  J=1,N)
      WRITE(6,10) ((T2(I,J),  I=1,11),DAY2(J),MO2(J),IYR2(J),  J=1,M)
      WRITE(6,10) ((T3(I,J),  I=1,11),DAY3(J),MO3(J),IYR3(J),  J=1,K)
C
C        COMPUTING THE NORM HEAT CONTENT FOR EACH MONTH
C
      CALL HEAT(TNORM,12,5,DNORM)
      DO 60 J=1,12
      DO 61 I=1,4
      QN(I,J)=Q(I,J)
      SN30(J)=SUM30(J)
      SN61(J)=SUM61(J)
      SN91(J)=SUM91(J)
      SN122(J)=SUM122(J)
   61 CONTINUE
   60 CONTINUE
C
C        COMPUTING THE AVERAGE BT FOR EACH MONTH
C
      CALL AVAGE(MO1,T1,N,MONTH,TAVE,KOUNT)
C
C        COMPUTING THE AVERAGE HEAT CONTENT IN EACH DEPTH LAYER
C        REFERENCED TO A BASE TEMPERATURE
C
```

```
      CALL HEAT(TAVE,MONTH,11,DEPTH)
C
C      COMPUTING THE HEAT AND TEMPERATURE ANOMALIES FOR EACH MONTH
C
      CALL ANOMLY(TAVE,TNORM,DNORM,KOUNT,SN30,SN61,SN91,SN122,
     $IYEAR1,QN,DEPTH,QA,SA,TAN,TITL2)
      CALL AVAGE(MO2,T2,M,MONTH,TAVE,KOUNT)
      CALL HEAT(TAVE,MONTH,11,DEPTH)
      CALL ANOMLY(TAVE,TNORM,DNORM,KOUNT,SN30,SN61,SN91,SN122,
     $IYEAR2,QN,DEPTH,QA,SA,TAN,TITL2)
      CALL AVAGE(MO3,T3,K,MONTH,TAVE,KOUNT)
      CALL HEAT(TAVE,MONTH,11,DEPTH)
      CALL ANOMLY(TAVE,TNORM,DNORM,KOUNT,SN30,SN61,SN91,SN122,
     $IYEAR3,QN,DEPTH,QA,SA,TAN,TITL2)
      STOP
      END


      SUBROUTINE SORT(N1,N2,N3,T,KK)
C
C        THIS SUBROUTINE IS USED TO ARRANGE THE BT'S BY DAY AND MONTH
C
      DIMENSION N1(KK),N2(KK),N3(KK),T(11,KK),TEMP(11,250)
      NPASS=KK-1
      DO 10 I=1,NPASS
      NSTOP=KK-I
      DO 10 J=1,NSTOP
      IF(N1(J).LE.N1(J+1)) GO TO 10
      NTEMP1=N1(J)
      NTEMP2=N2(J)
      NTEMP3=N3(J)
      N1(J)=N1(J+1)
      N2(J)=N2(J+1)
      N3(J)=N3(J+1)
      N1(J+1)=NTEMP1
      N2(J+1)=NTEMP2
      N3(J+1)=NTEMP3
      DO 20 L=1,11
      TEMP(L,J)=T(L,J)
      T(L,J)=T(L,J+1)
      T(L,J+1)=TEMP(L,J)
   20 CONTINUE
   10 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE SORT2(N1,N2,N3,T,KK)
      DIMENSION N1(KK),N2(KK),N3(KK),T(11,KK),TEMP(11,250)
      NPASS=KK-1
      DO 10 I=1,NPASS
      NSTOP=KK-I
      DO 10 J=1,NSTOP
      IF(N2(J).EQ.N2(J+1)) GO TO 30
      GO TO 10
   30 IF(N1(J).LE.N1(J+1)) GO TO 10
      NTEMP1=N1(J)
      NTEMP2=N2(J)
      NTEMP3=N3(J)
      N1(J)=N1(J+1)
      N2(J)=N2(J+1)
      N3(J)=N3(J+1)
      N1(J+1)=NTEMP1
      N2(J+1)=NTEMP2
      N3(J+1)=NTEMP3
      DO 20 L=1,11
      TEMP(L,J)=T(L,J)
      T(L,J)=T(L,J+1)
      T(L,J+1)=TEMP(L,J)
   20 CONTINUE
   10 CONTINUE
      RETURN
      END


      SUBROUTINE HEAT(T,L,LL,DEPTH)
C
C        THIS SUBROUTINE COMPUTES THE HEAT CONTENT IN EACH  DEPTH
C        INTERVAL
C
      DIMENSION T(11,L),DEPTH(LL)
      COMMON Q(10,250),QZ(10,250),SUM30(12),SUM61(12),SUM91(12),
     $SUM122(12),DIFF61(12),DIFF91(12),DIF122(12),TITLE(12),
     $ID1(4),ID2(4),IPOS(3)
      NR=LL-1
      DO 20 J=1,L
      SUM3=0.0
      SUM6=0.0
      SUM9=0.0
      SUM10=0.0
      DO 21 I=1,NR
      IF(T(I,J).LE.0.0) GO TO 20
      AVET=(T(I,J)+T(I+1,J))/2.0
      Z=DEPTH(I+1)-DEPTH(I)
C
```

```
C         COMPUTING THE HEAT CONTENT IN DEPTH LAYER
C
      Q(I,J)=AVET*Z*100.0/1.0E03
C
C         COMPUTING THE HEAT CONTENT PER METER IN DEPTH LAYER
C
      QZ(I,J)=AVET*100.0/1.0E03
C
C         COMPUTING THE CUMMULATIVE HEAT CONTENT FROM SURFACE TO 30 M,
C         SURFACE TO 61M, SURFACE TO 91M, AND SURFACE TO 122M (BOTTOM
C         OF LAYER)
C
      IF(NR.EQ.4) GO TO 30
      GO TO 40
   30 K1=1
      K2=2
      K3=3
      GO TO 31
   40 K1=4
      K2=6
      K3=8
   31 IF(I.GT.K1) GO TO 22
      SUM3=SUM3+Q(I,J)
   22 IF(I.GT.K2) GO TO 23
      SUM6=SUM6+Q(I,J)
   23 IF(I.GT.K3) GO TO 24
      SUM9=SUM9+Q(I,J)
   24 SUM10=SUM10+Q(I,J)
   21 CONTINUE
      SUM30(J)=SUM3
      SUM61(J)=SUM6
      SUM91(J)=SUM9
      SUM122(J)=SUM10
      DIFF61(J)=SUM61(J)-SUM30(J)
      DIFF91(J)=SUM91(J)-SUM61(J)
      DIF122(J)=SUM122(J)-SUM91(J)
   20 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE AVAGE(N1,T,NR,MONTH,TAVE,KOUNT)
C        THIS SUBROUTINE COMPUTES THE AVERAGE BT FOR DEPTHS OF 0,10,
C        20,25,30,50,61,75,91,100,AND 122 METERS.  DATA BT'S TO 91
C        METERS CAN BE USED IF "0.0" IS PUNCHED ON THE DATA CARD FOR
C        100 AND 122 METERS.
      DIMENSION N1(250),T0(12),T10(12),T20(12),T25(12),T30(12),
     $T50(12),T61(12),T75(12),T91(12),T100(12),T122(12),T(11,NR)
     $,KOUNT(12),TAVE(11,12),KOUNT1(12),KOUNT2(12)
      DO 50 I=1,12
      KOUNT1(I)=0
      KOUNT2(I)=0
   50 KOUNT(I)=0
      T0(1)=0.0
      T10(1)=0.0
      T20(1)=0.0
      T25(1)=0.0
      T30(1)=0.0
      T50(1)=0.0
      T61(1)=0.0
      T75(1)=0.0
      T91(1)=0.0
      T100(1)=0.0
      T122(1)=0.0
      J=1
      KOUNT(1)=0
      DO 10 I=1,NR
      IF(N1(I).EQ.J) GO TO 25
   26 J=J+1
      T0(J)=0.0
      T10(J)=0.0
      T20(J)=0.0
      T25(J)=0.0
      T30(J)=0.0
      T50(J)=0.0
      T61(J)=0.0
      T75(J)=0.0
      T91(J)=0.0
      T100(J)=0.0
      T122(J)=0.0
      KOUNT(J)=0
   20 IF(N1(I).EQ.J) GO TO 25
      GO TO 26
   25 KOUNT(J)=KOUNT(J)+1
   27 T0(J)=T0(J)+T(1,I)
      T10(J)=T10(J)+T(2,I)
      T20(J)=T20(J)+T(3,I)
```

```
      T25(J)=T25(J)+T(4,I)
      T30(J)=T30(J)+T(5,I)
      T50(J)=T50(J)+T(6,I)
      T61(J)=T61(J)+T(7,I)
      T75(J)=T75(J)+T(8,I)
      T91(J)=T91(J)+T(9,I)
      IF(T(10,I).LT.1.0) GO TO 10
      KOUNT1(J)=KOUNT1(J)+1
      T100(J)=T100(J)+T(10,I)
      IF(T(11,I).LT.1.0) GO TO 10
      KOUNT2(J)=KOUNT2(J)+1
      T122(J)=T122(J)+T(11,I)
   10 CONTINUE
      DO 30 I=1,J
      IF(KOUNT(I).EQ.0) GO TO 30
      COUNT1=KOUNT1(I)
      COUNT2=KOUNT2(I)
      COUNT=KOUNT(I)
      TAVE(1,I)=T0(I)/COUNT
      TAVE(2,I)=T10(I)/COUNT
      TAVE(3,I)=T20(I)/COUNT
      TAVE(4,I)=T25(I)/COUNT
      TAVE(5,I)=T30(I)/COUNT
      TAVE(6,I)=T50(I)/COUNT
      TAVE(7,I)=T61(I)/COUNT
      TAVE(8,I)=T75(I)/COUNT
      TAVE(9,I)=T91(I)/COUNT
      TAVE(10,I)=T100(I)/COUNT1
      TAVE(11,I)=T122(I)/COUNT2
   30 CONTINUE
      MONTH=J
      RETURN
      END


      SUBROUTINE ANOMLY(TAVE,TNORM,DNORM,KOUNT,SN30,SN61,SN91,
     $SN122,IYR,QN,DEPTH,QA,SA,TAN,TITL2)
C
C       THIS SUBROUTINE COMPUTES THE TEMPERATURE AND HEAT CONTENT
C       ANOMALIES FOR EACH MONTH OF THE YEAR
C       MONTH=NO. OF MONTHS OF BT DATA IN THE SAME YEAR
C       TAVE=ARRAY CONTAINING THE MEAN BT'S FOR EACH MONTH (MAX OF 12 )
C       TNORM=ARRAY CONTAINING THE MONTHLY LONG PERIOD NORM BT
C       DNORM=DEPTHS AT WHICH TEMPS FOR TNORM ARE RECORDED
C       KOUNT= ARRAY CONTAINING THE NO OF BTS THAT WENT INTO COMPUTING
C       EACH MONTHLY BT IN TAVE
C       SN30,SN61,SN91,SN122 ARE CUMMULATIVE HEAT CONTENT VALUES FOR EACH
C       DEPTH LAYER
```

```
C
C        TAN = ARRAY OF TEMPERATURE ANOMALIES
C        QA = ARRAY OF HEAT CONTENT ANOMALIES IN DEPTH LAYERS OF
C        0-30, 30-61, 61-91, AND 91-122 METERS.
C        SA = ARRAY OF HEAT CONTENT ANOMALIES IN DEPTH LAYERS 0-30,
C        0-61, 0-91, 0-122 METERS.

      DIMENSION TAVE(11,12),TNORM(11,12),DNORM(5),KOUNT(12),QA(4,12),
     $SA(4,12),TAN(5,12),QN(4,12),DEPTH(11),SN30(12),SN61(12),SN91(12),
     $SN122(12),TITL2(6)
      CCMMON Q(10,250),QZ(10,250),SUM30(12),SUM61(12),SUM91(12),
     $SUM122(12),DIFF61(12),DIFF91(12),DIF122(12),TITLE(12),
     $ID1(4),ID2(4),IPOS(3)
      REAL*8 ID1,ID2
      REAL*8 TITL2
      DO 150 J=1,12
      IF(KOUNT(J).EQ.0) GO TO 140
      WRITE(6,10) (TITL2(I), I=1,6)
      WRITE(6,151) TITLE(J),IYR,TITLE(J),IYR,KOUNT(J)
      WRITE(6,152) (DEPTH(I),TAVE(I,J), I=1,11)
      WRITE(7,200) (TAVE(I,J), I=1,11),(IPOS(I), I=1,3),TITLE(J)
  200 FORMAT(11F5.1,2X,3A4,2X,A3)
      WRITE(6,95)
      WRITE(6,100) (QZ(I,J), I=1,10)
      WRITE(6,50)
      WRITE(6,101) SUM30(J),SUM61(J),SUM91(J),SUM122(J),SUM30(J),
     $DIFF61(J),DIFF91(J),DIF122(J)
      NN=1
      DO 153 I=1,5
      IF(I.NE.2) GO TO 154
      NN=5
  154 TAN(I,J)=TAVE(NN,J)-TNORM(I,J)
      NN=NN+2
  153 CONTINUE
      QA(1,J)=SUM30(J)-QN(1,J)
      QA(2,J)=DIFF61(J)-QN(2,J)
      QA(3,J)=DIFF91(J)-QN(3,J)
      QA(4,J)=DIF122(J)-QN(4,J)
      SA(1,J)=SUM30(J)-SN30(J)
      SA(2,J)=SUM61(J)-SN61(J)
      SA(3,J)=SUM91(J)-SN91(J)
      SA(4,J)=SUM122(J)-SN122(J)
      WRITE(6,155)
      WRITE(6,156) (DNORM(I),TAN(I,J),ID1(I),SA(I,J),ID2(I),QA(I,J), I=1
     $,4)
      WRITE(6,157) (DNORM(I),TAN(I,J), I=5,5)
      GO TO 150
  140 DO 130 I=1,5
```

```
130 TAN(I,J)=99.9
    DO 131 I=1,4
    QA(I,J)=99.9
131 SA(I,J)=99.9
    WRITE(6,141) TITLE(J),IYR
141 FORMAT('1',50X,'NO DATA AVAILABLE FOR',1X,1A3,2X,I4)
150 CONTINUE
    DO 500 I=1,5
500 WRITE(7,110) (TAN(I,J), J=1,12), DNORM(I),IYR
    DO 501 I=1,4
    WRITE(7,111) (SA(I,J), J=1,12),ID1(I),IYR
501 WRITE(7,111) (QA(I,J), J=1,12),ID2(I),IYR
110 FORMAT(12F5.1,5X,F5.1,5X,I4)
111 FORMAT(12F5.1,2X,1A8,5X,I4)
 10 FORMAT('1',44X,6A8,//)
151 FORMAT(55X,1A3,2X,I4,///,40X,'THE AVERAGE BT FOR ',2X,1A3,2X,
   $I4,10X,'NO. OF BTS',//,45X,'DEPTH(M)',5X,'TEMP(DEG C.)',10X,'USED
   * (',I2,')',//)
152 FORMAT(46X,F5.1,8X,F5.1,/)
 95 FORMAT(/,43X,'HEAT CONTENT IN EACH LAYER IN KCAL/CM**2/METER',
   $//,20X,'0-10',5X,'10-20',5X,'20-25',5X,'25-30',5X,'30-50',5X,
   $'50-61',5X,'61-75',5X,'75-91',5X,'91-100',4X,'100-122',//)
100 FORMAT(14X,10F10.1,//)
 50 FORMAT(//,20X,'CUMMULATIVE HEAT (KCAL/CM**2)',26X,'HEAT CONTENT IN
   $ EACH 30 METER LAYER',//,21X,'0-30',6X,'0-61',6X,'0-91',
   $6X,'0-122',18X,'0-30',7X,'30-61',3X,'61-91',5X,'91-122',//)
101 FORMAT(15X,4F10.1,13X,4F10.1,//)
155 FORMAT(///,50X,'ANOMALIES',//,10X,'DEPTH(M)',10X,'TEMPERATURE(DEG
   $C.)',10X,'DEPTH LAYER',5X,'HEAT',5X,'DEPTH LAYER',5X,'HEAT',/,
   $69X,'(KCAL/CM**2)',16X,'(KCAL/CM**2)',//)
156 FORMAT(11X,F5.1,17X,F5.1,16X,1A8,6X,F8.1,7X,1A8,6X,F8.1,//)
157 FORMAT(11X,F5.1,17X,F5.1)
    RETURN
    END
//GO.SYSIN  DD  *
```

```
*         DATA SECTION (NOTE: * INDICATES EXPLANATORY CARD AND IS NOT PART OF THE
*         DATA)
*
*     TNORM.........LONG TERM MEAN
*
 18.6 18.5 18.4 18.4 18.2                                          30-00N     140-00W            JAN
 18.3 18.3 18.2 18.2 18.1                                          30-00N     140-00W            FEB
 18.5 18.4 18.4 18.2 17.9                                          30-00N     140-00W            MAR
 18.8 18.6 18.4 18.3 17.8                                          30-00N     140-00W            APR
 19.4 19.0 18.4 18.2 17.8                                          30-00N     140-00W            MAY
 20.4 19.8 18.8 18.3 17.7                                          30-00N     140-00W            JUN
 21.8 20.9 19.4 18.6 17.4                                          30-00N     140-00W            JUL
 22.9 22.1 19.9 18.5 17.1                                          30-00N     140-00W            AUG
 23.3 22.9 20.4 18.3 16.9                                          30-00N     140-00W            SEP
 22.8 22.7 21.1 18.6 17.1                                          30-00N     140-00W            OCT
 21.3 21.3 20.9 19.2 17.7                                          30-00N     140-00W            NOV
 19.6 19.6 19.6 19.2 18.1                                          30-00N     140-00W            DEC
*
*     TITLE ...... USED IN OUTPUT
*
JANFEBMARAPRMAYJUNJULAUGSEPOCTNOVDEC
*
*     SAMPLE BT FORMAT IN DEG C..........................DATE.....LAT..LONG..TIME
 15.8 15.8 15.8 15.8 15.8 14.6 12.7 11.4 10.8 10.5  9.9 181264   3348 12800  600
*
*     DEPTHS IN METERS
*
  0.0 10.0 20.0 25.0 30.0 50.0 61.0 75.0 91.0100.0122.0
    0-30    0-61     0-91    0-122
    0-30   30-61    61-91   91-122
STATION NOVEMBER(30-00N,140-00W)
3000N 14000W
```

Tabulation of Heat Content Value in the Surface Layer

Station U

Year	Month	Heat Content (kcal/cm^2) 0-30m	0-61m	0-91m	0-122m
1950	Dec	66.3	134.8	199.8	231.3
1951	Jan	66.6	135.0	200.2	232.2
	Feb	61.4	124.6	185.2	215.4
	Mar	57.8	117.3	174.5	202.8
	Apr	59.0	119.2	176.6	204.8
	May	60.6	121.3	178.0	205.7
	Jun	67.5	135.1	197.4	227.6
	Jul	69.8	139.2	230.1	234.0
	Aug	71.0	143.6	210.7	242.5
	Sep	72.1	144.5	209.9	240.4
	Oct	72.5	146.3	213.3	244.2
	Nov	71.5	145.2	213.4	245.2
1964	Jan	64.4	131.0	195.4	258.1
	Mar	58.9	119.1	173.5	222.5
	Apr	57.0	115.6	171.9	229.7
	May	73.0	148.1	220.1	292.3
	Dec	68.5	132.1	194.5	257.1
1965	Apr	62.2	126.0	187.2	250.0
	Jun	67.9	135.5	198.2	260.7
	Jul	65.5	132.4	193.2	253.8
	Nov	65.4	133.0	197.7	260.7
	Dec	63.2	128.2	190.7	253.0
1966	Jan	61.5	121.9	175.9	228.5
	Feb	63.3	128.7	192.0	256.0
	Jun	66.9	131.7	188.1	243.1
	Jul	68.9	137.5	198.4	257.2
	Aug	69.4	138.8	198.4	256.1
	Sep	69.6	140.7	203.9	263.6

Year	Month	Heat Content (kcal/cm^2) 0-30m	0-61m	0-91m	0-122m
1966	Oct	68.7	139.5	201.7	259.7
	Nov	66.9	136.1	200.5	261.2
	Dec	66.4	134.6	198.2	255.8
1967	Feb	65.5	132.7	196.1	259.6
	Mar	60.0	121.8	180.5	239.2
	Apr	60.0	121.4	180.0	238.3
	May	61.7	123.2	181.1	238.4
	Jun	61.7	122.1	177.2	231.8
	Jul	70.4	139.6	201.2	261.6
	Aug	72.3	145.7	210.0	271.8
	Sep	75.4	146.5	207.8	266.4
	Oct	74.6	147.7	209.4	267.5
	Nov	67.6	137.3	202.0	262.3
	Dec	64.2	130.5	194.3	255.2
1968	Jan	63.6	129.4	192.6	254.4
	Feb	61.2	124.3	185.4	245.9
	Mar	59.6	120.8	179.6	238.5
	Apr	61.8	125.4	185.9	246.5
	May	66.0	132.0	193.3	253.7
	Jun	70.4	136.3	195.5	253.8
	Jul	74.3	144.6	207.6	269.0
	Aug	75.2	146.8	208.2	266.9
	Sep	76.0	149.6	212.7	274.7
	Nov	72.9	143.6	205.9	264.6
	Dec	64.8	131.8	194.8	252.8
1969	Jan	63.3	128.7	192.0	254.0
	Feb	63.0	128.1	191.1	254.0
	Mar	58.7	119.3	177.6	236.8

Station U (Cont'd)

Heat Content (kcal/cm^2)

Year	Month	0-30m	0-61m	0-91m	0-122m
1969	Apr	60.2	121.3	179.5	238.5
	May	64.6	129.2	189.1	248.5
	Jun	66.8	132.1	191.6	250.1
	Jul	72.1	142.5	205.2	267.2
	Aug	68.6	138.2	201.3	261.7
	Sep	72.1	145.6	210.1	272.0
	Oct	71.8	144.7	209.0	269.4
	Nov	69.3	140.5	198.5	244.5
	Dec	67.5	137.2	204.1	266.7
1970	Jan	62.1	126.5	188.7	250.4
	Feb	60.2	122.3	181.9	242.1
	Mar	58.2	117.4	173.0	228.9
	Apr	59.5	120.1	176.6	232.5
	Jun	65.7	130.0	188.4	246.2

Station N

Heat Content (kcal/cm^2)

Year	Month	0-30m	0-61m	0-91m	0-122m
1946	Jul	63.9	125.0	180.7	208.1
	Aug	68.2	133.2	191.5	220.1
	Sep	67.8	133.2	191.4	220.0
	Oct	66.6	131.6	188.8	215.9
	Nov	62.1	126.2	185.7	213.9
1947	Jan	55.4	112.7	168.2	196.0
	Feb	56.0	113.9	170.0	198.0
	Mar	56.1	113.9	169.7	196.6
	May	57.9	117.2	174.1	202.4
	Jun	60.0	119.7	176.0	203.9
	Jul	65.5	129.5	188.8	217.7
	Aug	67.4	132.3	192.0	220.6
	Sep	69.4	136.0	193.8	221.2
1948	Jan	58.8	119.6	178.3	207.6
	Feb	56.7	115.3	172.0	200.4
	Apr	56.2	113.8	169.2	196.9
	May	58.2	116.2	170.6	197.3
	Jun	61.2	121.6	176.9	203.8
	Jul	65.0	128.7	186.1	213.9
	Aug	67.4	134.6	194.6	222.7
	Oct	68.2	136.1	196.7	224.9
	Nov	66.0	134.0	196.9	226.9
	Dec	60.8	123.8	184.4	214.4
1949	Feb	51.4	104.2	155.5	181.1
	Apr	54.2	109.8	163.4	190.0
	Jun	59.6	119.4	175.3	202.7
	Jul	62.3	124.4	181.6	209.4
	Aug	65.3	128.9	186.2	213.5
	Sep	68.2	133.5	191.0	218.3
	Nov	64.9	131.9	192.9	220.8
	Dec	58.4	119.2	175.9	202.3
1950	Jan	56.2	114.3	170.8	198.9
	Mar	57.6	117.1	174.5	203.1
	May	57.4	117.2	174.8	203.6

Heat Content (kcal/cm^2)

Year	Month	0-30m	0-61m	0-91m	0-122m
1965	Jan	57.8	117.5	173.9	226.5
	Mar	57.2	115.8	172.1	230.1
	Apr	54.3	109.4	162.4	217.3
	May	56.2	113.1	167.1	221.4
	Jun	59.6	118.5	173.0	227.4
	Jul	65.2	129.6	188.1	246.4
	Aug	68.9	135.4	194.6	251.9
	Sep	69.4	136.7	196.2	254.6
	Oct	67.0	134.7	194.0	252.1
	Nov	60.7	122.8	181.2	239.3
	Dec	57.1	116.1	173.2	231.7
1966	Jan	54.4	110.6	164.9	220.9
	Feb	53.9	109.6	163.6	219.3
	Jul	64.4	127.3	184.3	240.6
	Sep	65.5	131.0	188.0	242.6
	Oct	67.9	137.0	197.4	253.7
	Nov	64.1	130.2	191.6	247.6
1967	Jan	53.5	108.7	162.0	215.9
	Feb	54.0	109.7	163.4	218.4
	Mar	55.3	112.3	167.4	224.0
	Apr	54.9	111.5	166.0	222.0
	May	53.7	108.6	161.4	215.2
	Jun	61.0	121.3	176.3	231.5
	Jul	62.5	122.8	176.6	230.0
	Aug	67.9	126.6	179.2	232.2
	Sep	72.2	138.7	194.4	247.9
	Oct	70.9	140.4	198.9	253.5
	Nov	65.7	132.2	189.2	242.7
	Dec	58.8	119.5	178.1	235.4
1968	Jan	58.0	117.9	175.9	235.1
	Feb	57.4	116.5	173.5	231.8
	Mar	54.9	111.5	165.9	221.3
	Apr	56.4	114.4	170.2	227.4
	May	57.7	115.6	171.1	227.9

Station N (Cont'd)

Heat Content (kcal/cm^2)

Year	Month	0-30m	0-61m	0-91m	0-122m
1968	Jun	66.3	129.2	185.9	241.8
	Jul	69.2	135.2	193.1	250.0
	Aug	72.6	140.3	198.4	255.2
	Sep	72.4	141.1	198.4	253.5
	Nov	64.8	131.8	194.1	250.4
	Dec	60.5	122.9	183.4	242.0
1969	Jan	62.7	127.5	190.3	254.0
	Feb	57.0	116.1	173.3	232.2
	Mar	51.4	104.5	155.8	208.8
	Apr	54.4	110.5	164.6	219.9
	May	58.2	116.8	172.4	228.2
	Jun	62.9	123.9	180.1	236.4
	Jul	66.2	131.6	190.4	247.9
	Aug	65.5	131.5	189.8	245.5
	Sep	64.3	129.2	185.0	237.6
	Oct	66.5	134.7	194.7	249.8
	Nov	66.0	133.9	196.4	254.1
	Dec	59.1	120.1	177.3	231.4
1970	Feb	53.4	108.4	161.6	216.3

Station 4

Year	Month	Heat Content (kcal/cm^2) 0-30m	0-61m	0-91m	0-122m
1950	Dec	55.3	112.2	164.6	189.1
1951	Jan	52.0	105.4	156.6	181.8
	Feb	52.0	105.7	157.1	182.6
	Mar	50.2	101.8	151.3	175.9
	Apr	51.0	103.4	153.9	179.0
	May	49.6	99.3	146.8	170.6
	Jun	51.0	101.5	148.2	171.2
	Jul	56.2	109.5	157.7	181.0
	Aug	64.7	126.7	181.1	206.9
	Sep	66.9	130.4	185.1	211.4
	Oct	64.7	127.3	181.8	207.2
1963	Feb	48.0	97.6	145.6	190.9
	Mar	44.8	90.4	130.0	167.0
	Apr	50.4	102.3	141.3	204.0
	May	52.5	104.8	154.8	205.6
	Jun	55.2	110.2	160.5	211.4
	Jul	56.7	110.9	159.4	208.0
	Aug	66.6	130.6	181.2	228.1
	Oct	65.1	128.3	181.2	232.2
	Dec	49.3	101.5	152.6	201.4
1964	Jan	53.9	109.7	161.2	210.3
	Mar	53.2	108.2	161.5	216.7
	Apr	50.8	103.3	154.2	207.0
	May	51.1	104.0	155.2	208.0
	Jun	51.4	102.0	150.6	200.3
	Jul	57.3	110.6	161.3	213.1
1965	May	45.5	91.7	136.0	181.0
	Jun	60.6	119.4	176.8	237.0
	Jul	60.1	120.3	174.4	228.9
	Aug	64.2	125.1	178.4	233.1
	Oct	61.5	114.9	160.4	204.7
	Dec	55.0	112.1	166.4	218.3
1966	Jan	51.7	104.4	155.5	208.0
1966	Jun	51.4	101.6	147.5	193.8
	Jul	57.2	110.8	158.2	204.9
	Aug	59.6	113.5	160.6	206.0
	Oct	59.9	119.1	168.1	124.0
	Nov	58.8	118.9	170.1	217.9
1967	Jan	50.8	104.2	155.9	202.7
	Feb	48.0	97.9	147.2	197.0
	Mar	48.4	97.5	143.8	190.2
	Apr	45.0	91.5	136.5	176.9
	May	46.0	91.5	134.0	175.3
	Jun	48.9	95.5	139.0	183.1
	Jul	59.4	118.0	166.9	216.7
	Aug	65.5	123.8	174.3	224.7
	Sep	66.8	121.8	167.9	212.5
	Oct	65.8	126.2	174.6	220.7
	Nov	60.6	119.7	169.1	216.1
	Dec	51.3	104.2	150.7	192.5
1968	Jan	51.1	103.5	153.9	204.4
	Feb	48.6	98.8	146.5	192.4
	Mar	47.5	96.1	142.3	186.8
	Apr	47.6	96.2	142.2	186.5
	May	49.7	98.6	145.2	191.4
	Jun	57.8	109.3	157.5	205.1
	Jul	65.4	121.0	170.9	220.6
	Aug	64.9	122.5	171.4	218.0
	Oct	69.8	135.9	191.7	247.2
	Nov	62.5	126.3	180.9	231.5
	Dec	56.5	115.1	171.0	223.7
1969	Jan	52.3	106.3	157.6	203.6
	Feb	53.1	108.0	161.1	215.1
	Mar	47.9	97.2	145.1	194.3
	Apr	47.8	96.7	143.8	191.2
	May	51.1	102.2	151.1	200.3

Station 4 (Cont'd)

Heat Content (kcal/cm^2)

Year	Month	0-30m	0-61m	0-91m	0-122m
1969	Jun	49.2	94.1	134.6	173.7
	Jul	62.0	121.5	174.5	226.4
	Aug	60.4	119.5	169.3	218.1
	Sep	64.3	127.5	181.5	232.6
	Oct	68.2	134.2	185.9	232.9
	Nov	60.5	122.7	176.5	226.1
	Dec	54.9	111.7	166.2	217.3
1970	Jan	53.2	102.3	144.6	183.7
	Feb	55.6	112.6	167.2	222.7
	Mar	48.2	98.0	146.7	195.7
	Apr	46.2	94.2	140.2	185.0
	May	53.7	105.6	153.4	200.6
	Jun	56.4	111.4	162.2	212.7

Station 18

Year	Month	Heat Content ($kcal/cm^2$) 0-30m	0-61m	0-91m	0-122m
1963	Feb	48.5	98.3	146.0	190.8
	Apr	49.8	101.3	151.1	202.2
	May	51.7	103.4	153.2	204.5
	Jun	54.3	108.5	158.4	208.2
	Jul	55.9	109.7	157.8	206.2
	Aug	57.6	115.3	162.0	205.7
	Oct	63.7	125.5	177.1	227.1
	Nov	54.5	100.9	137.3	173.0
	Dec	56.3	114.1	167.3	217.9
1964	Jan	55.4	112.4	166.2	219.2
	Feb	45.0	91.5	136.3	180.5
	Apr	49.1	100.1	149.5	200.2
	May	49.0	99.8	149.2	200.0
	Jun	52.1	103.9	153.0	203.2
	Jul	55.9	109.3	158.0	207.6
	Aug	60.6	115.7	164.9	215.1
	Sep	61.1	119.4	170.1	221.0
	Oct	60.5	119.9	171.4	221.3
	Dec	52.5	107.5	155.9	202.1
1965	Mar	47.4	96.4	143.8	191.6
	May	42.8	86.5	128.3	170.0
	Jun	53.6	107.2	158.0	210.2
	Jul	58.2	116.0	170.9	227.7
	Aug	61.7	116.1	161.8	205.7
	Oct	58.7	111.5	157.6	202.3
	Nov	62.3	124.1	179.4	233.3
	Dec	52.4	107.1	159.5	208.8
1966	Jan	47.8	98.3	147.5	198.4
	Jun	52.5	102.4	148.0	194.5
	Jul	58.8	112.3	160.6	207.6
	Aug	58.8	116.3	163.8	208.4
	Sep	62.0	123.0	175.9	227.1
	Oct	59.9	119.4	169.7	217.3
	Nov	56.7	115.3	166.9	213.1

Year	Month	Heat Content ($kcal/cm^2$) 0-30m	0-61m	0-91m	0-122m
1967	Jan	48.8	99.7	147.5	193.7
	Feb	47.1	96.2	143.8	191.2
	Mar	49.6	100.3	148.6	196.3
	Apr	46.4	95.0	142.7	188.3
	May	53.2	105.7	154.9	205.1
	Jul	57.1	112.7	163.9	214.6
	Aug	62.1	121.0	173.8	225.3
	Oct	61.8	115.1	157.9	200.6
	Nov	65.3	129.0	182.2	233.6
1968	Jan	50.4	102.4	152.6	200.2
	Feb	47.0	95.0	140.6	184.8
	Mar	50.2	101.9	151.9	201.3
	Apr	49.1	99.5	148.4	195.9
	May	50.7	102.7	152.7	203.8
	Jun	54.3	102.9	148.2	193.1
	Jul	61.2	116.6	168.2	219.9
	Aug	63.4	120.8	172.1	224.3
	Nov	57.5	113.6	160.2	205.7
	Dec	53.1	108.3	160.3	207.9
1969	Jan	50.3	102.2	150.1	194.0
	Feb	54.3	110.4	164.7	218.9
	Mar	51.0	103.7	154.7	206.7
	Apr	52.7	106.4	157.6	209.3
	May	50.5	101.1	148.7	196.6
	Jun	43.5	77.9	107.3	135.5
	Jul	59.8	116.9	166.6	216.5
	Aug	57.7	111.8	158.6	204.3
	Sep	64.2	125.4	176.7	226.3
	Oct	63.7	125.2	177.1	224.4
	Nov	59.8	121.0	173.4	222.2
	Dec	60.3	122.6	182.9	238.4
1970	Jan	50.6	102.9	152.9	201.0
	Feb	56.4	114.2	169.2	224.0
	Mar	48.6	98.7	148.0	197.0

Station 18 (Cont'd)

		Heat Content (kcal/cm^2)			
Year	Month	0-30m	0-61m	0-91m	0-122m
1970	Apr	47.8	97.4	146.2	196.6
	Jun	55.6	109.2	158.0	206.3

Station 16

Year	Month	Heat Content ($kcal/cm^2$) 0-30m	0-61m	0-91m	0-122m
1962	Apr	45.7	91.0	130.8	164.7
	Jul	52.5	102.4	144.9	183.7
	Sep	55.6	110.0	156.3	200.7
	Oct	62.1	125.2	178.4	227.4
	Nov	54.3	107.9	153.1	193.2
	Dec	49.1	98.5	140.4	177.9
1963	Jan	50.5	102.6	150.0	192.5
	Feb	51.9	105.5	157.2	204.0
	Mar	52.3	106.5	158.9	210.7
	May	48.9	98.7	146.3	193.9
	Jun	50.9	102.7	150.1	196.0
	Jul	52.0	103.1	148.6	191.0
	Aug	55.3	110.6	157.2	202.2
	Sep	65.3	128.6	183.7	234.9
	Oct	62.7	123.3	173.8	220.2
	Nov	56.9	115.9	170.4	219.4
	Dec	56.3	114.4	169.3	221.0
1964	Jan	55.1	111.5	164.5	217.0
	Feb	47.4	95.2	140.1	184.6
	Mar	44.0	89.7	134.1	178.4
	Apr	45.5	92.4	137.8	184.4
	May	45.7	91.5	135.7	180.6
	Jun	49.2	97.1	142.3	189.1
	Jul	42.4	104.2	149.4	194.9
	Aug	58.3	111.6	156.9	202.0
	Sep	58.5	113.8	161.7	209.3
	Oct	58.1	116.3	169.1	219.3
	Nov	52.7	106.3	156.6	206.9
	Dec	49.0	99.7	148.8	199.7
1965	Jan	42.4	84.8	121.6	156.2
	Feb	44.8	91.1	133.1	171.0
	Apr	44.2	87.6	127.5	166.7
	May	43.0	85.2	124.1	160.1

Year	Month	Heat Content ($kcal/cm^2$) 0-30m	0-61m	0-91m	0-122m
1965	Jun	49.2	98.8	145.8	193.1
	Oct	56.0	107.5	151.1	192.1
	Nov	57.7	114.2	164.6	214.2
	Dec	50.2	99.6	142.5	182.3
1966	Jan	45.0	91.5	135.1	173.8
	Feb	43.5	88.7	132.5	178.1
	Jul	55.8	108.6	154.2	198.1
	Aug	55.0	109.3	155.4	199.0
	Sep	57.1	110.3	153.9	196.7
	Oct	56.0	112.6	159.5	201.3
	Nov	57.7	114.9	161.3	204.3
1967	Jan	44.3	90.4	134.7	178.1
	Feb	39.9	83.1	122.5	158.7
	Apr	43.5	89.1	132.7	173.6
	May	48.4	98.0	145.6	194.6
	Jun	49.9	100.9	148.4	194.4
	Jul	53.6	105.2	150.6	196.0
	Aug	53.4	103.8	147.7	190.6
	Sep	67.8	126.9	179.0	230.0
	Nov	59.2	117.4	164.8	210.5
	Dec	45.8	93.3	136.1	169.1
1968	Jan	46.6	93.8	138.0	178.8
	Feb	45.5	91.9	135.5	177.4
	Apr	46.2	92.7	136.8	178.6
	May	46.4	92.5	136.3	179.5
	Jun	52.7	101.2	144.9	185.8
	Jul	56.5	107.5	149.7	188.8
	Aug	55.5	104.4	147.1	186.3
	Sep	62.1	115.7	158.8	197.8
	Oct	56.2	113.3	156.3	193.3
	Nov	57.6	117.1	169.0	214.2
	Dec	52.0	104.2	149.6	190.2
1969	Jan	47.9	97.3	143.9	184.3

Station 16 (Cont'd)

		Heat Content (kcal/cm^2)			
Year	Month	0-30m	0-61m	0-91m	0-122m
1969	Feb	44.5	90.3	134.3	176.8
	Mar	45.5	92.5	137.8	182.9
	Apr	42.1	85.0	124.9	163.8
	May	46.1	90.9	133.3	174.5
	Jun	46.9	90.5	128.6	164.2
	Jul	53.9	104.8	148.4	189.5
	Aug	53.0	105.0	147.2	186.8
	Sep	55.7	109.3	152.8	192.6
	Oct	50.5	98.1	134.0	165.9
	Nov	53.9	109.5	157.2	200.0
1970	Jan	47.3	95.5	140.0	182.1
	Feb	48.3	97.9	144.5	188.6
	Mar	47.3	95.7	141.6	185.6
	Apr	45.9	92.9	137.7	180.3
	Jun	48.3	93.9	132.8	167.3
	Aug	63.0	124.9	179.0	233.0
	Sep	59.1	116.2	164.5	212.1
	Oct	54.0	106.6	150.2	190.3

Station 19

Year	Month	Heat Content ($kcal/cm^2$) 0-30m	0-61m	0-91m	0-122m
1962	Aug	54.9	106.0	148.3	186.4
	Oct	59.8	120.8	173.7	223.2
	Nov	55.6	111.8	157.7	199.9
	Dec	53.0	107.5	155.5	198.1
1963	Jan	51.2	104.0	151.8	194.4
	Feb	51.8	105.1	155.9	202.9
	Mar	53.2	108.2	161.6	215.4
	Apr	49.9	101.3	150.7	199.7
	May	49.5	100.2	148.2	196.4
	Jun	51.4	103.2	150.9	197.2
	Jul	53.0	104.7	150.9	195.3
	Aug	56.0	111.1	159.1	204.2
	Oct	63.1	125.7	180.2	230.3
	Nov	59.3	120.0	174.7	226.1
	Dec	56.7	115.2	171.0	224.2
1964	Jan	51.3	104.9	156.9	206.4
	Feb	48.0	97.5	145.3	191.8
	Mar	46.1	94.0	140.4	186.7
	Apr	45.9	93.4	139.4	186.8
	May	49.0	98.5	146.4	194.3
	Jun	53.4	106.2	155.8	206.3
	Jul	54.4	107.6	156.2	204.8
	Aug	59.4	116.0	167.0	217.4
	Sep	58.4	113.8	162.2	210.2
	Oct	57.0	113.2	163.4	211.5
	Dec	54.8	111.2	162.3	206.9
1965	Jan	52.4	106.5	157.6	202.7
	Feb	50.7	103.2	153.6	202.5
	Mar	49.8	101.5	152.1	204.1
	Apr	50.2	101.8	151.6	203.2
	May	49.1	99.5	147.8	197.4
	Jun	50.0	100.3	147.8	197.4
	Aug	56.8	107.2	149.9	190.0

Year	Month	Heat Content ($kcal/cm^2$) 0-30m	0-61m	0-91m	0-122m
1965	Oct	57.3	111.3	157.6	201.2
	Nov	58.0	114.6	164.8	214.0
	Dec	52.5	106.0	154.3	201.1
1966	Jan	48.5	98.7	147.1	193.7
	Feb	43.5	88.7	132.5	178.1
	Jul	60.3	118.0	168.9	219.1
	Aug	57.2	113.6	160.9	207.9
	Sep	54.5	108.1	150.8	190.7
	Oct	57.9	117.0	166.6	212.7
	Nov	57.4	113.9	160.6	204.9
1967	Jan	47.5	97.5	146.0	194.1
	Mar	51.2	104.1	156.0	209.1
	Apr	45.0	91.5	135.5	178.5
	May	49.4	99.7	147.7	194.9
	Jun	52.3	105.3	155.5	205.8
	Jul	56.1	111.9	161.3	210.7
	Aug	58.4	114.9	164.4	210.8
	Sep	62.9	119.0	167.1	214.4
	Oct	63.9	123.0	173.3	222.7
	Nov	61.8	123.4	174.8	223.2
1968	Jan	50.3	102.2	151.7	198.9
	Feb	49.4	100.3	148.8	196.9
	Mar	48.8	97.8	143.5	187.8
	Apr	48.8	99.0	146.6	190.6
	May	47.8	95.0	139.8	183.6
	Jun	56.3	109.2	158.8	207.6
	Jul	58.6	112.1	160.7	208.4
	Aug	60.9	115.1	161.9	204.7
	Oct	64.4	123.8	175.3	225.6
	Nov	63.2	128.0	185.9	241.2
	Dec	60.0	122.4	182.1	238.9
1969	Jan	51.5	105.1	155.2	201.8
	Feb	50.6	103.0	153.9	205.0

Station 19 (Cont'd)

		Heat Content ($kcal/cm^2$)			
Year	Month	0-30m	0-61m	0-91m	0-122m
1969	Mar	47.5	95.7	141.8	186.8
	Apr	49.5	100.0	148.3	197.1
	May	50.5	102.1	151.9	202.3
	Jun	58.1	114.4	166.2	216.9
	Jul	56.7	112.0	160.4	207.8
	Aug	56.3	113.3	162.9	212.3
	Sep	57.1	113.9	162.4	208.2
	Oct	61.6	123.3	177.5	227.2
	Nov	55.4	112.5	162.5	207.3
	Dec	54.0	109.3	160.4	208.1
1970	Jan	53.6	109.0	162.6	213.1
	Feb	50.2	101.8	151.1	199.1
	Mar	50.3	101.8	151.1	199.3
	Apr	47.7	96.9	145.0	194.2

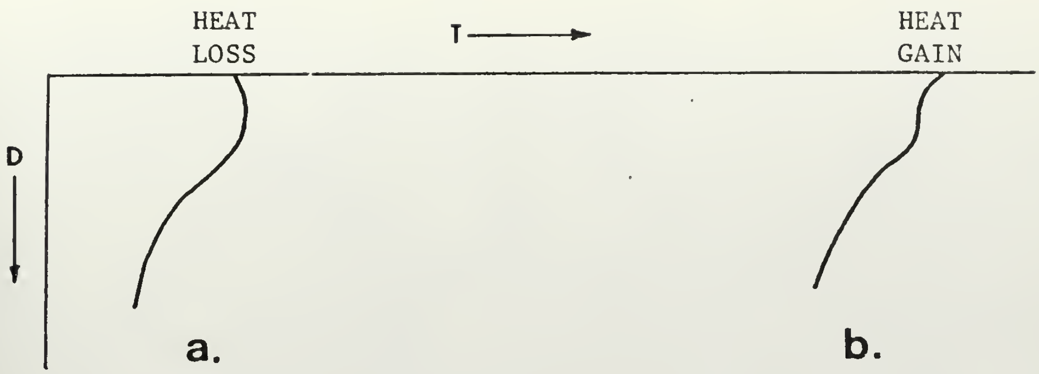


FIGURE 1. EFFECTS OF HEAT EXCHANGE ON VERTICAL TEMPERATURE STRUCTURE [after La Fond 1954].

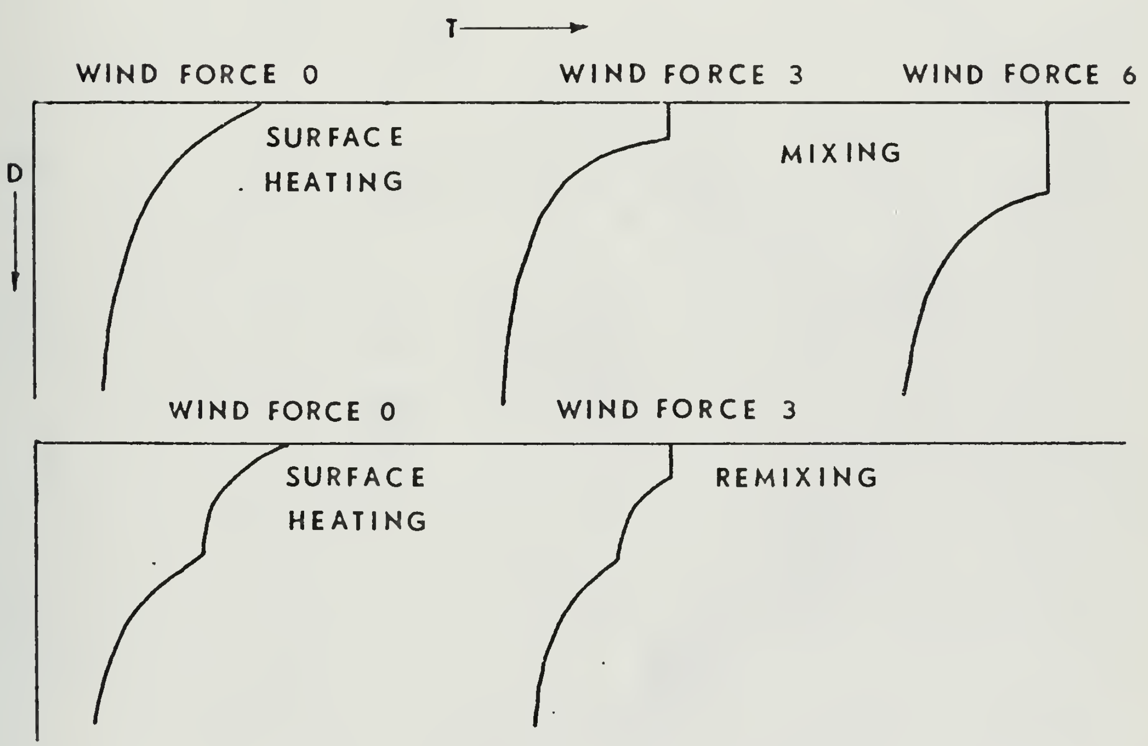


FIGURE 2. EFFECTS OF DIFFERENT WIND FORCES ON VERTICAL TEMPERATURE STRUCTURE [after La Fond 1954].

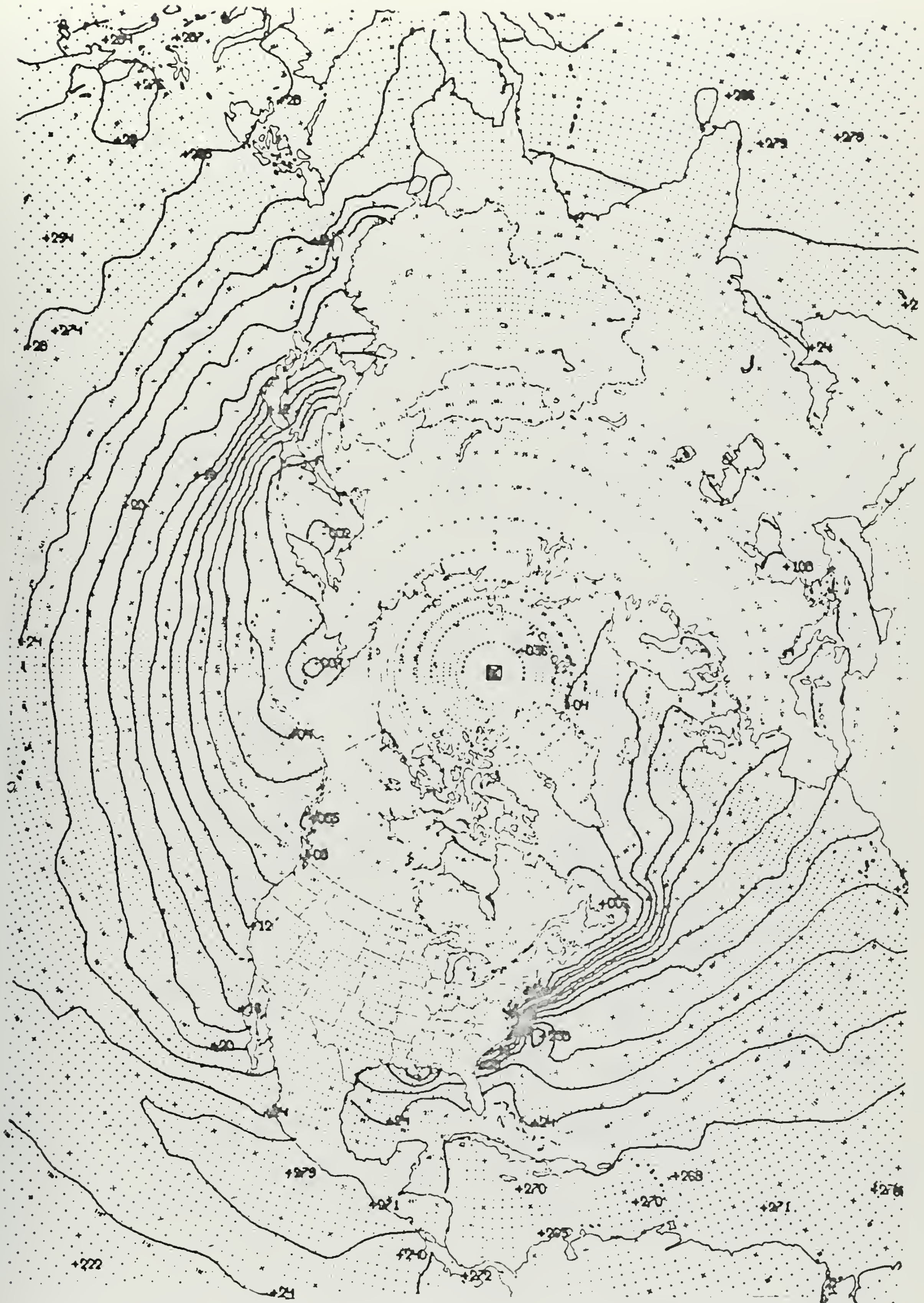


FIGURE 3. FNWC'S 30-DAY MEAN SST ANALYSIS FOR JANUARY 1971.

FIGURE 4. FNWC'S 30-DAY SST ANOMALY FOR JANUARY 1971.

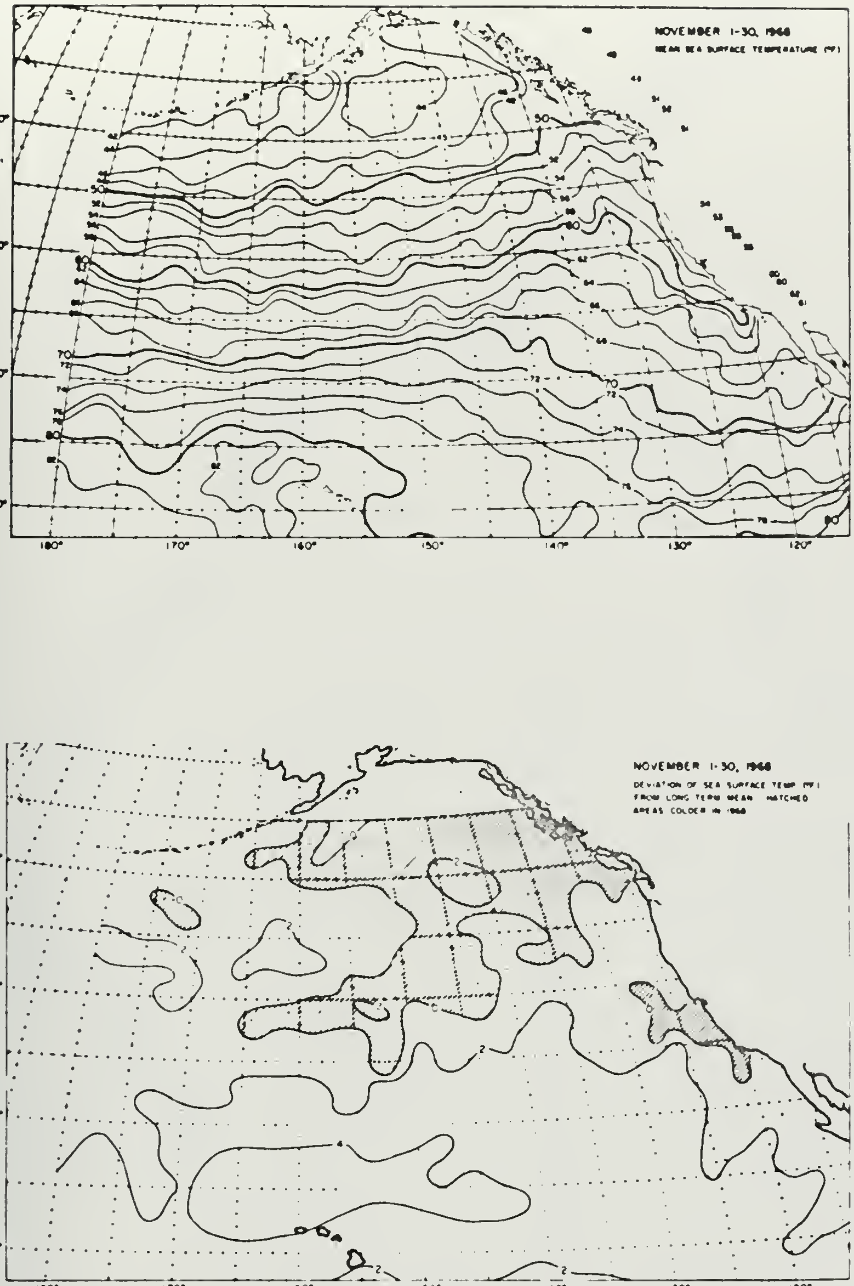


FIGURE 5. SAMPLE CHARTS OF SST AND SST ANOMALIES FOR NOVEMBER 1968 [after Renner 1968].

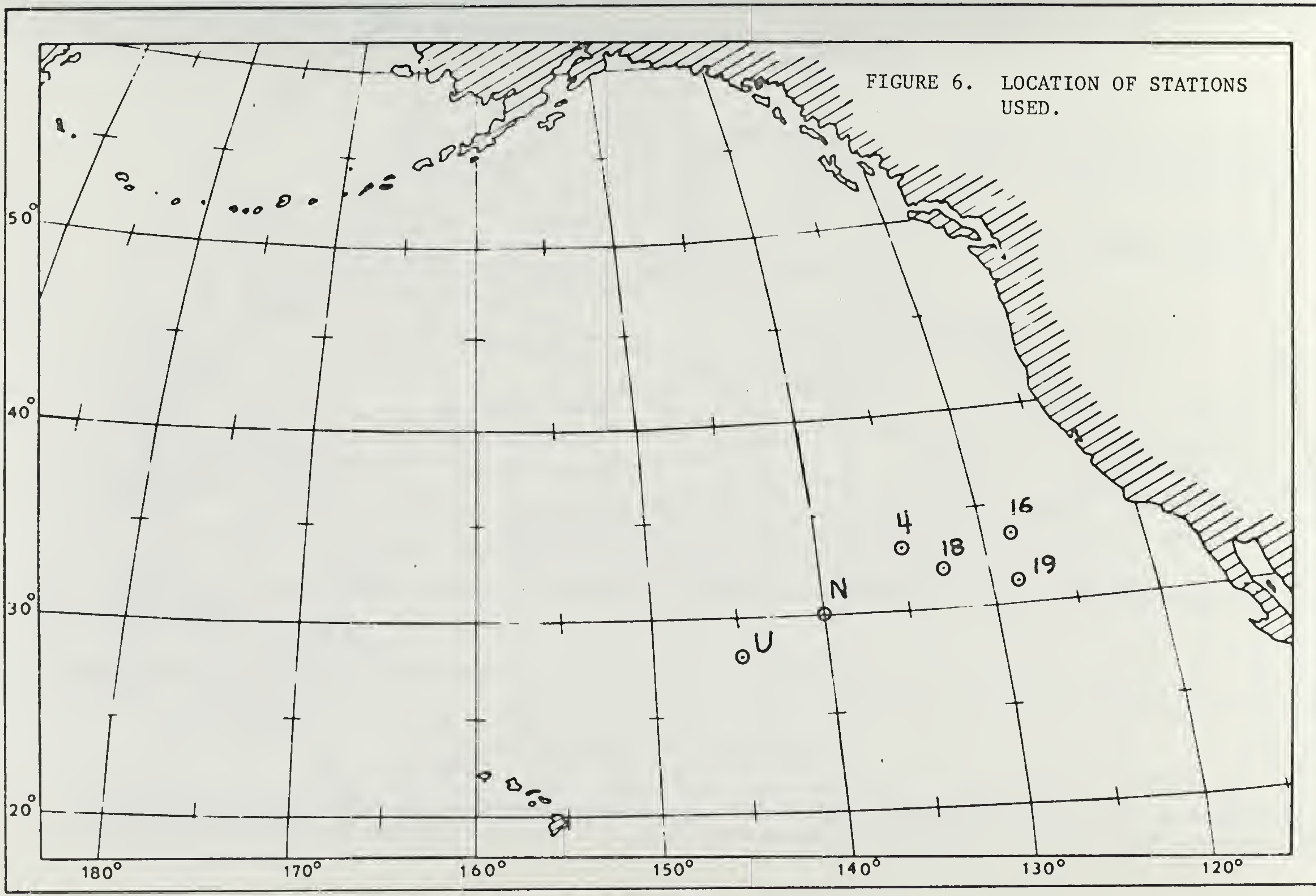


FIGURE 6. LOCATION OF STATIONS USED.

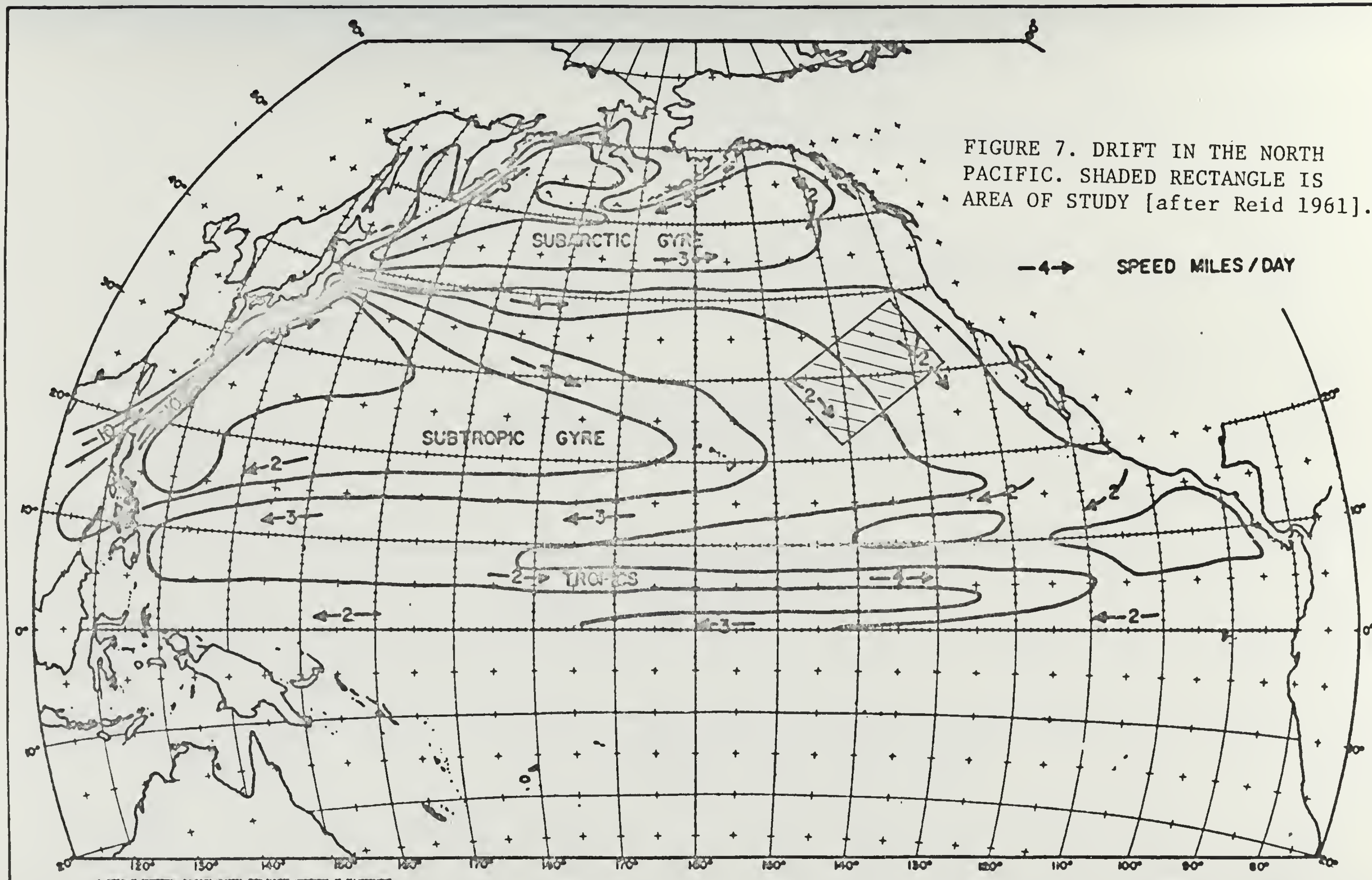


FIGURE 7. DRIFT IN THE NORTH PACIFIC. SHADED RECTANGLE IS AREA OF STUDY [after Reid 1961].

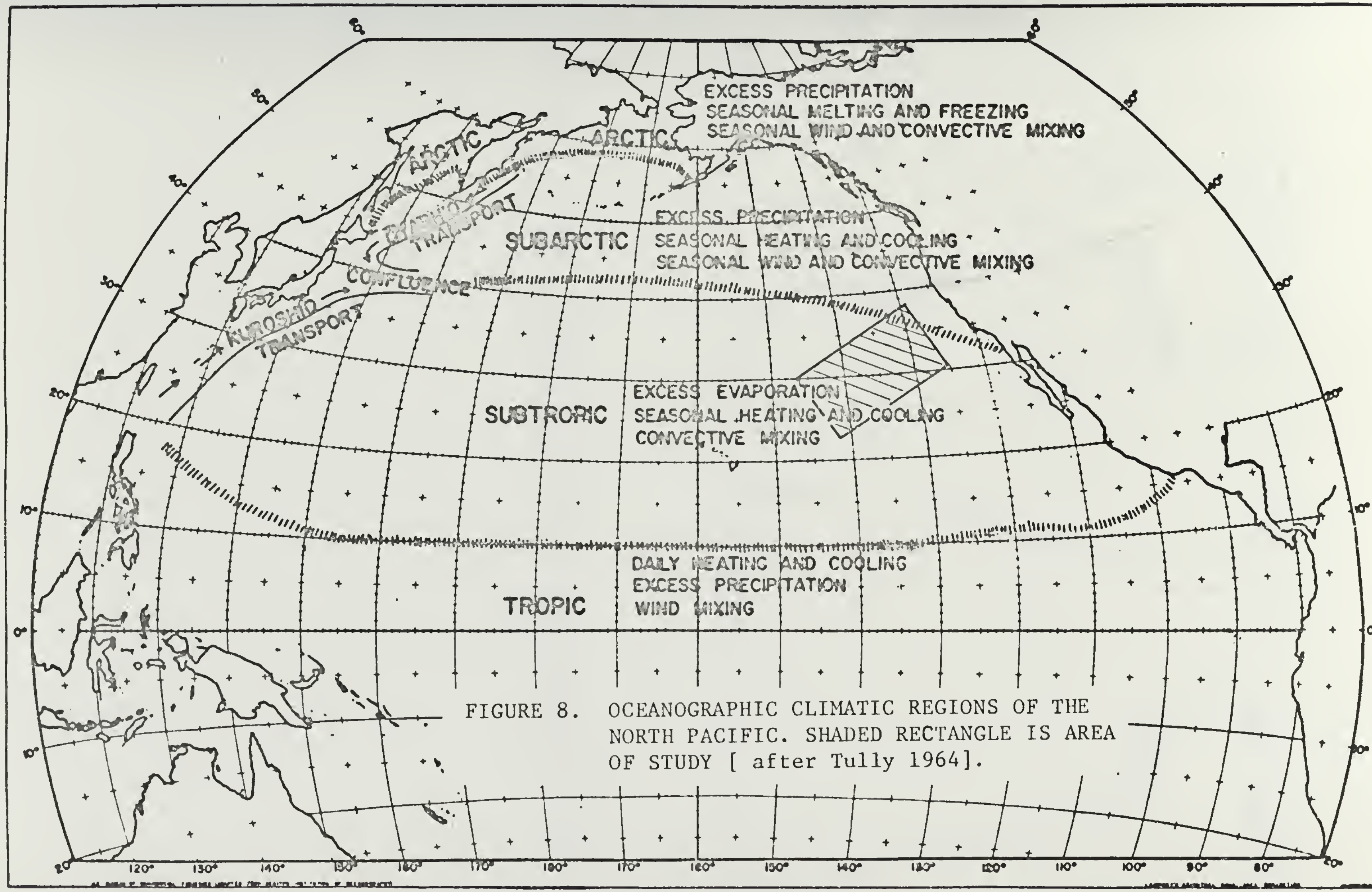


FIGURE 8. OCEANOGRAPHIC CLIMATIC REGIONS OF THE NORTH PACIFIC. SHADED RECTANGLE IS AREA OF STUDY [after Tully 1964].

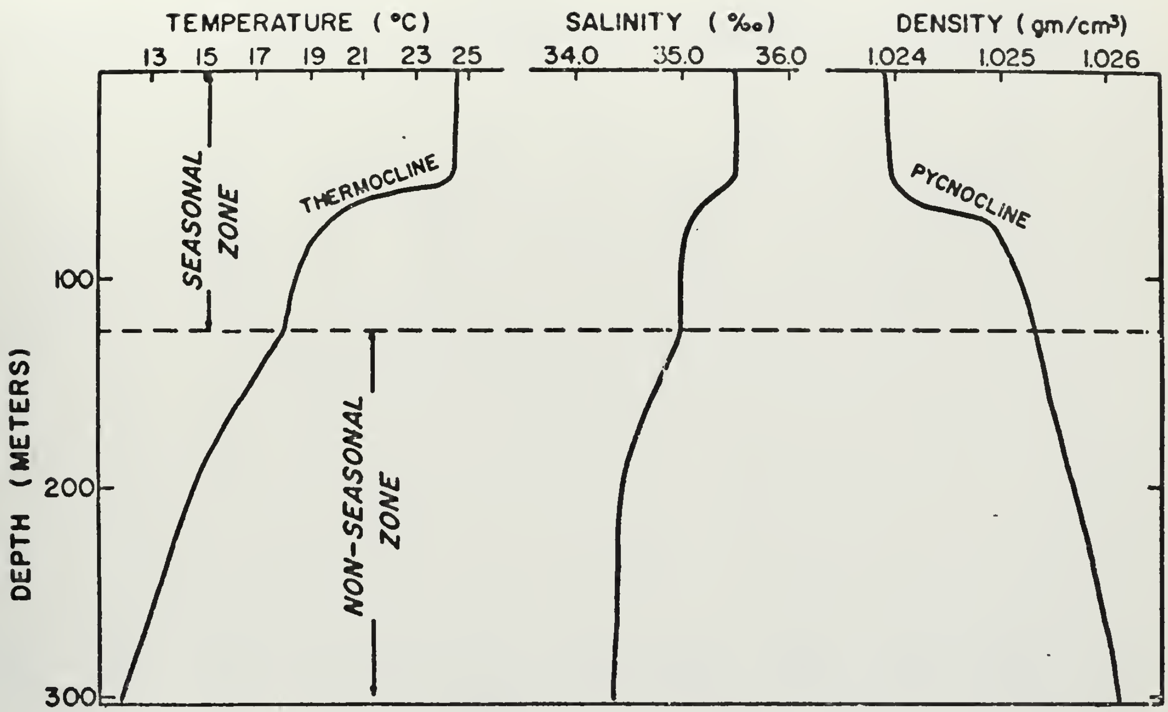
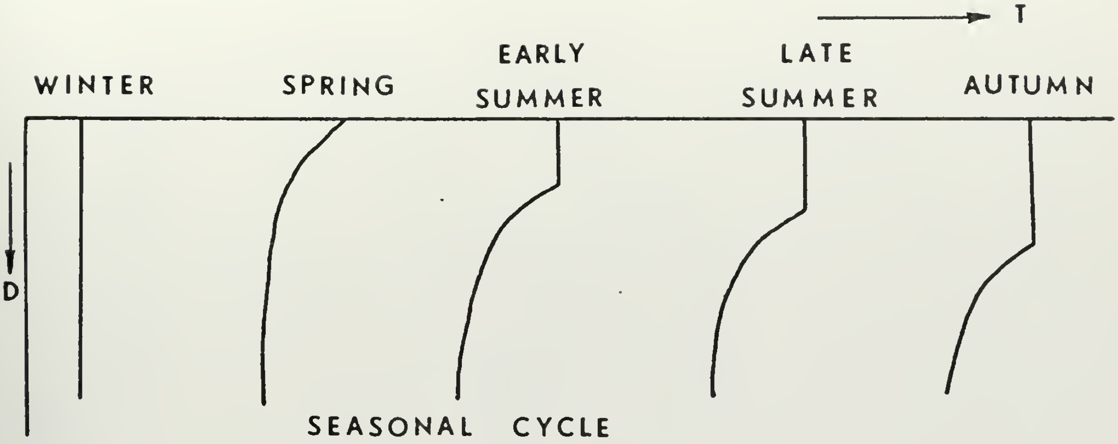


FIGURE 9. TYPICAL TEMPERATURE, SALINITY, AND DENSITY STRUCTURES IN THE SUBTROPIC REGION [after Tully 1964].



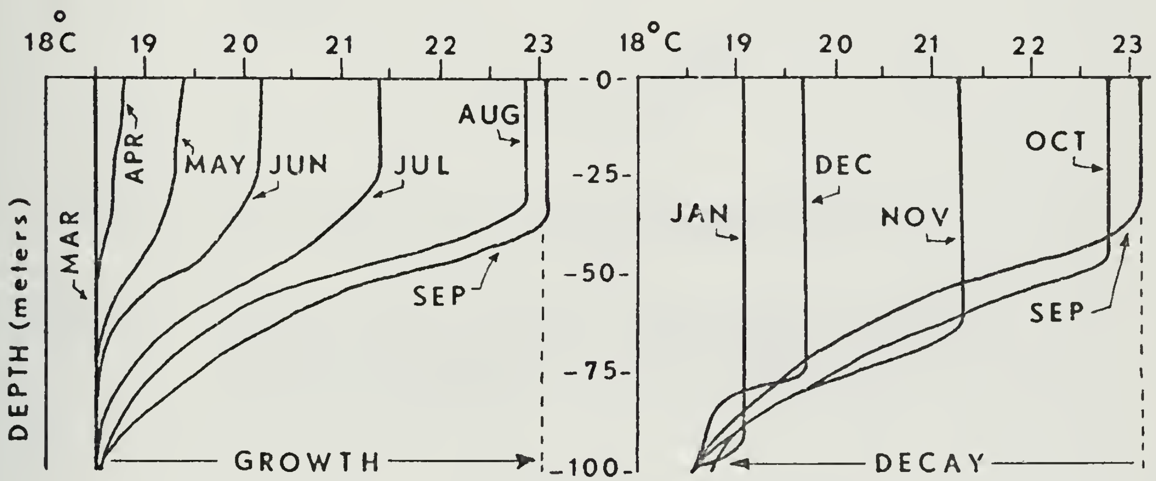


FIGURE 10. SEASONAL TYPES OF VERTICAL THERMAL STRUCTURE (SCHEMATIC) AND GROWTH AND DECAY OF THE THERMOCLINE AT OCEAN STATION N.

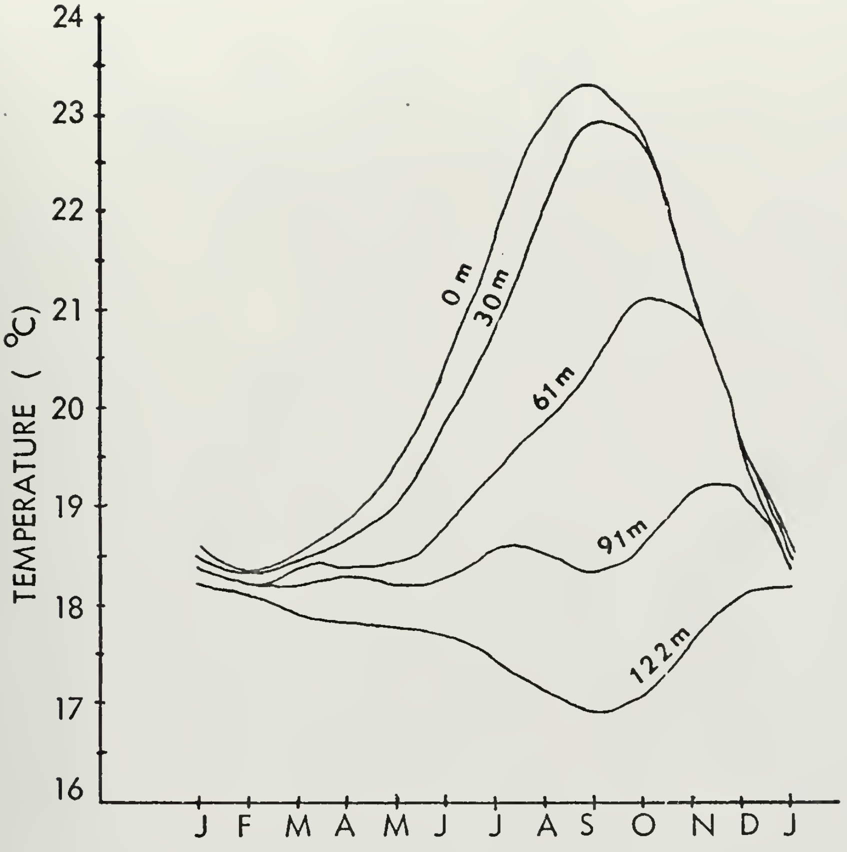


FIGURE 11. SMOOTHED AVERAGE ANNUAL TEMPERATURE CYCLES FOR STATION N (30°N,140°W) AT THE SURFACE, 30, 61, 91, and 122 METERS.

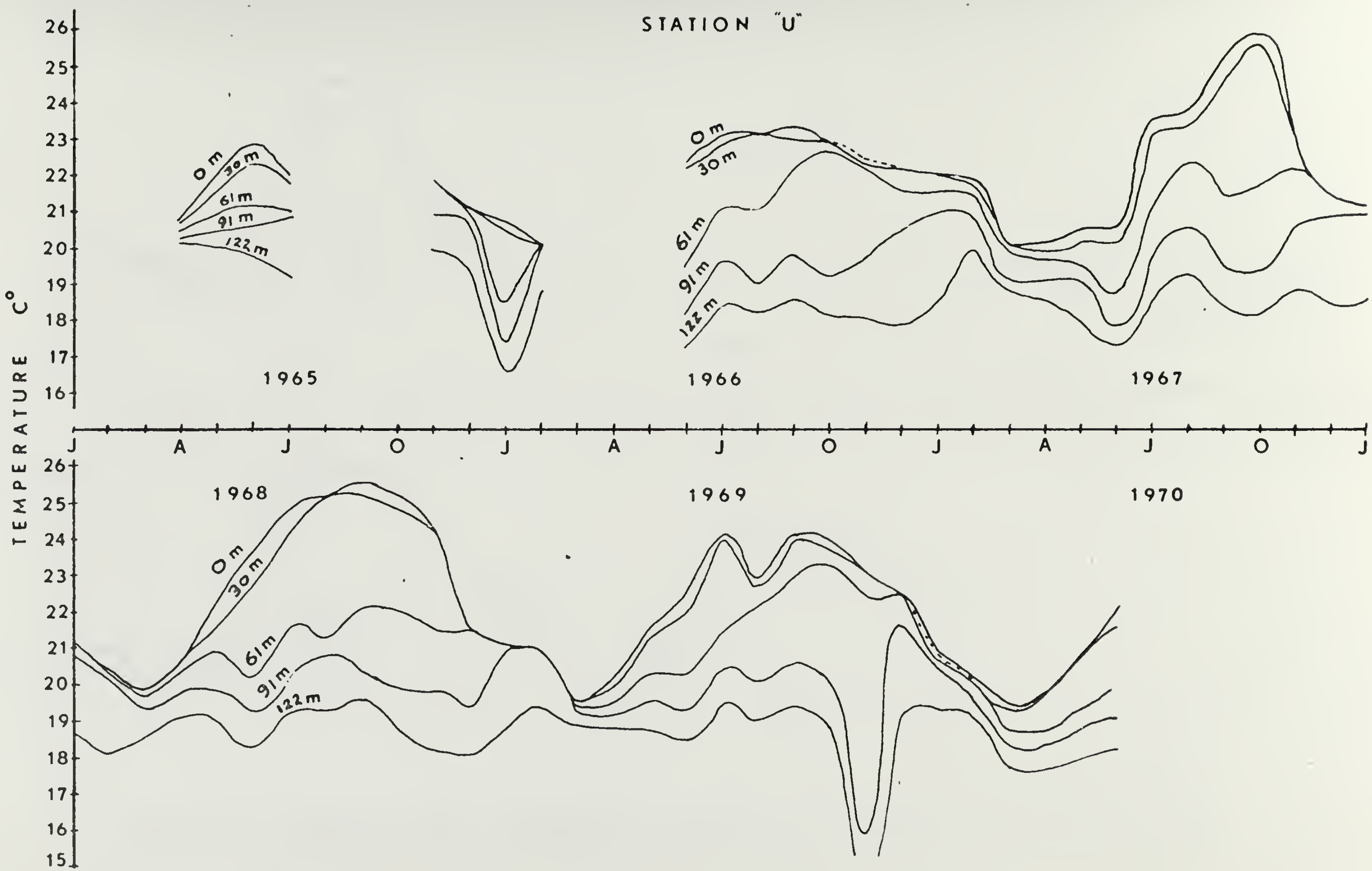


FIGURE 12. OBSERVED ANNUAL TEMPERATURE VARIATIONS FOR STATION U (28°N,145°W) AT THE SURFACE, 30, 61, 91, AND 122 METERS.

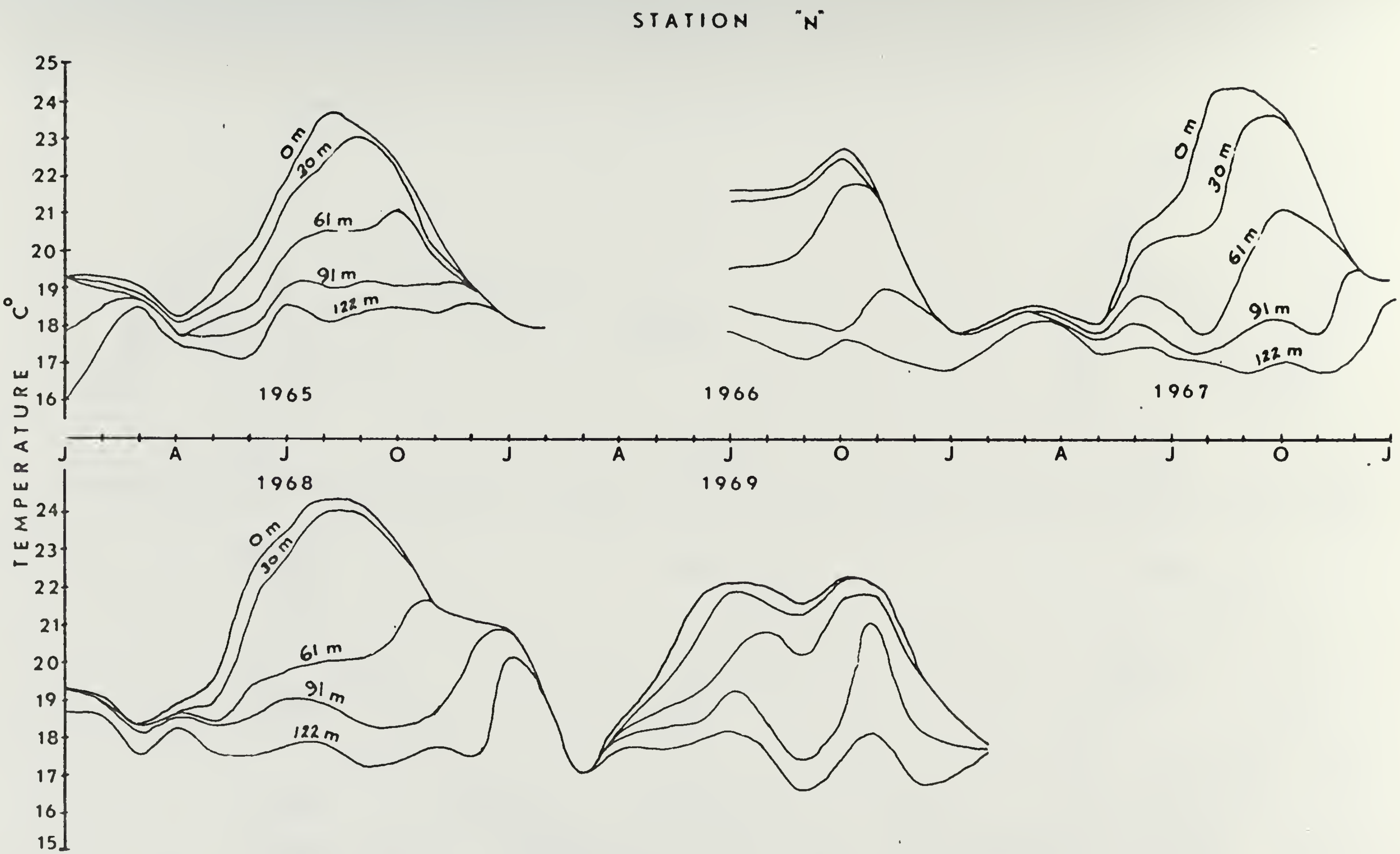


FIGURE 13. OBSERVED ANNUAL TEMPERATURE VARIATIONS FOR STATION N ($30^{\circ}N, 140^{\circ}W$) AT THE SURFACE, 30, 61, 91, AND 122 METERS.

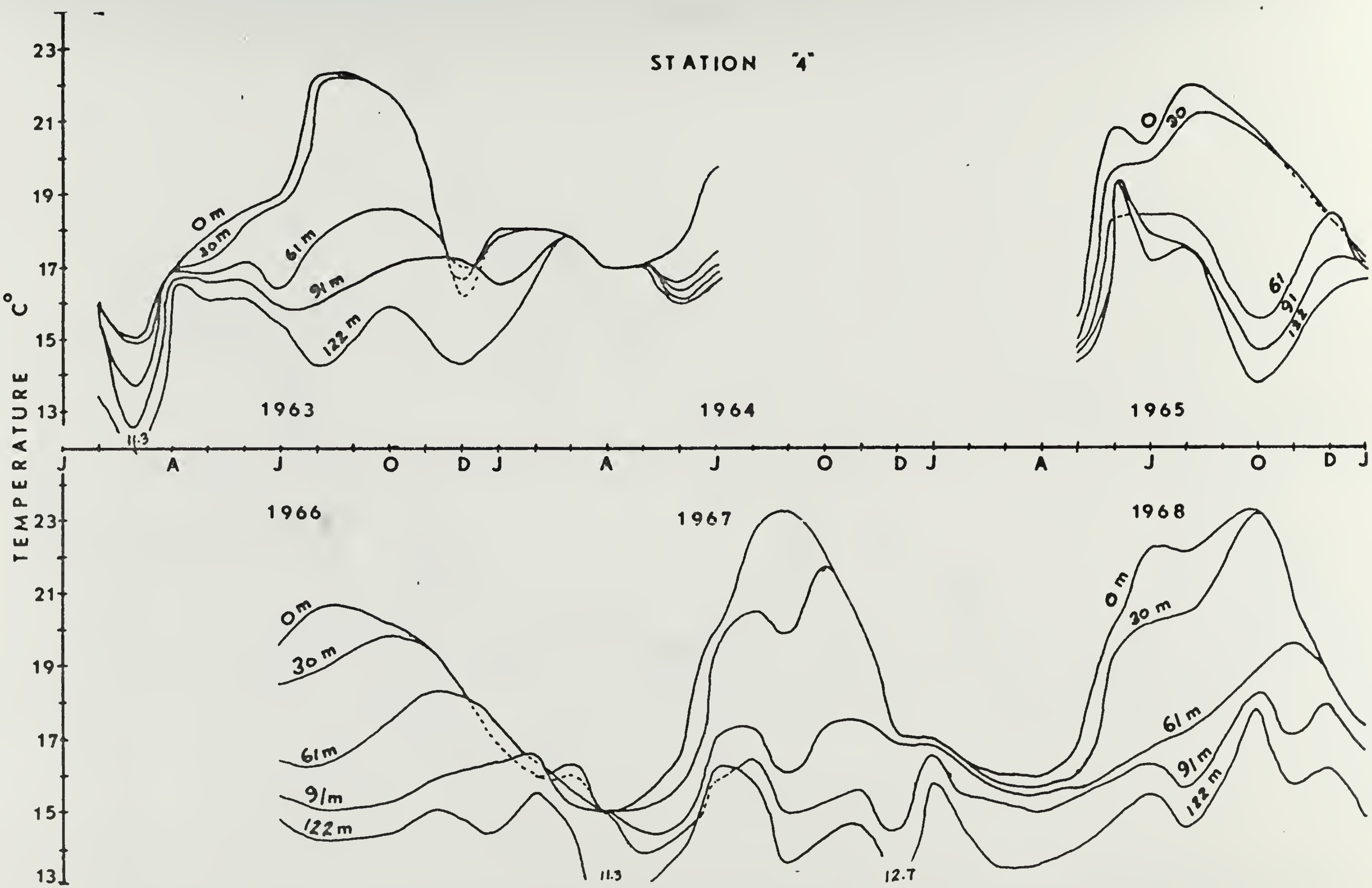


FIGURE 14. OBSERVED ANNUAL TEMPERATURE VARIATIONS FOR STATION 4 (33^{O}N,135^{O}W) AT THE SURFACE, 30, 61, 91, AND 122 METERS.

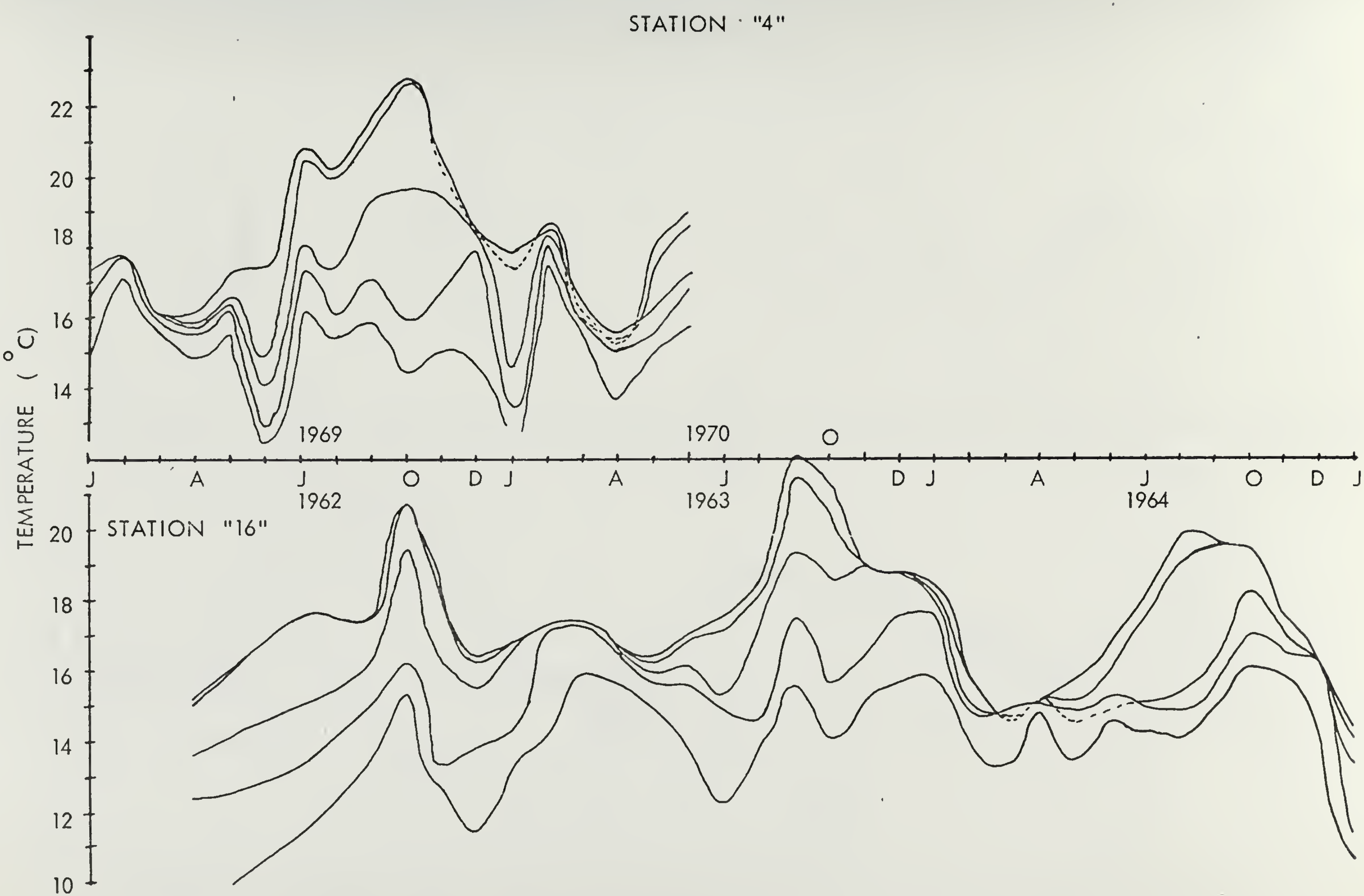


FIGURE 15. OBSERVED ANNUAL TEMPERATURE VARIATIONS FOR STATIONS 4 (33^{o}N,135^{o}W) AND 16 (33^{o}-23'N,128^{o}-38'W) AT THE SURFACE, 30, 61, 91, AND 122 METERS.

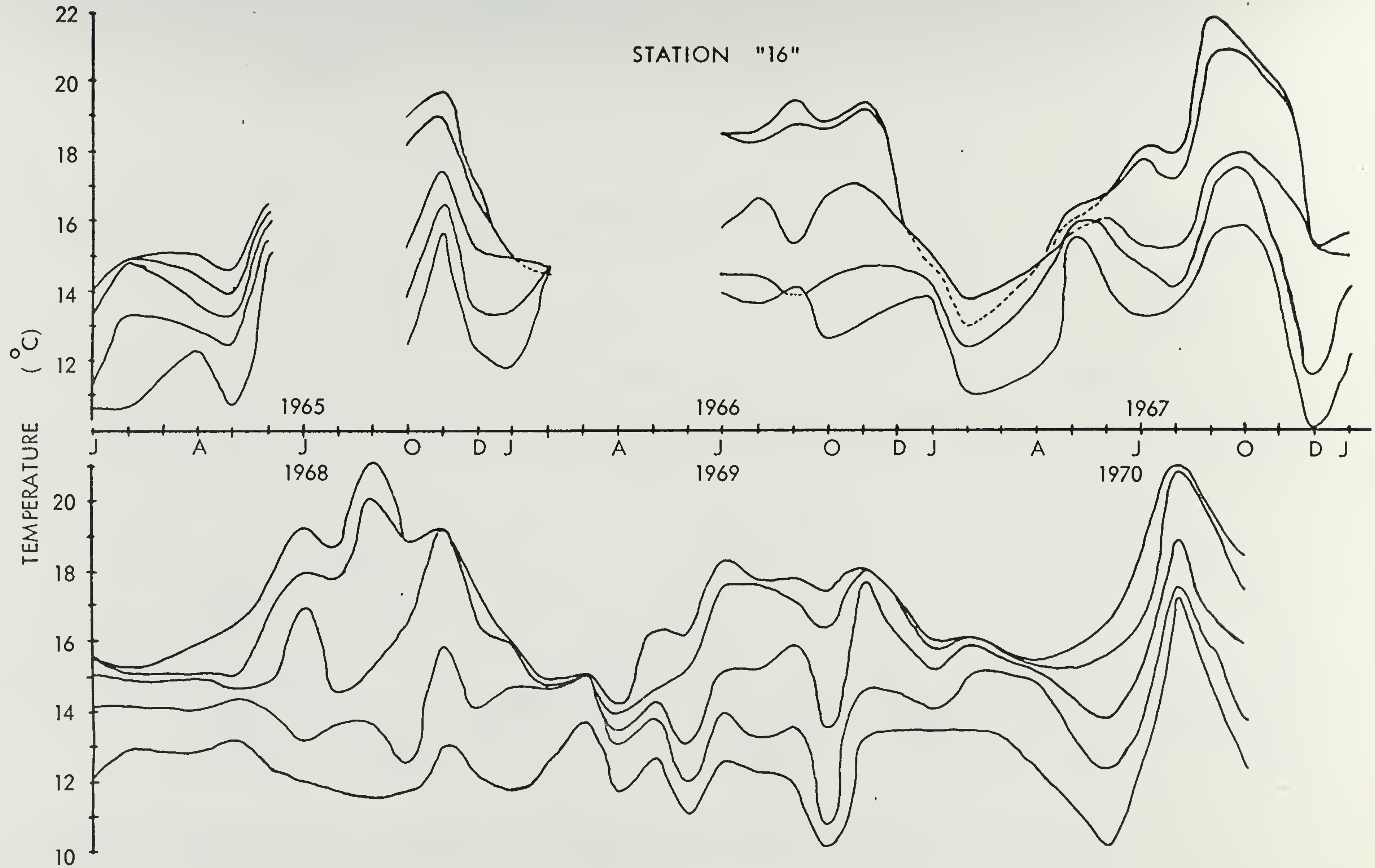


FIGURE 16. OBSERVED ANNUAL TEMPERATURE VARIATIONS FOR STATION 16 (33°-23'N,128°-38'W) AT THE SURFACE, 30, 61, 91, AND 122 METERS.

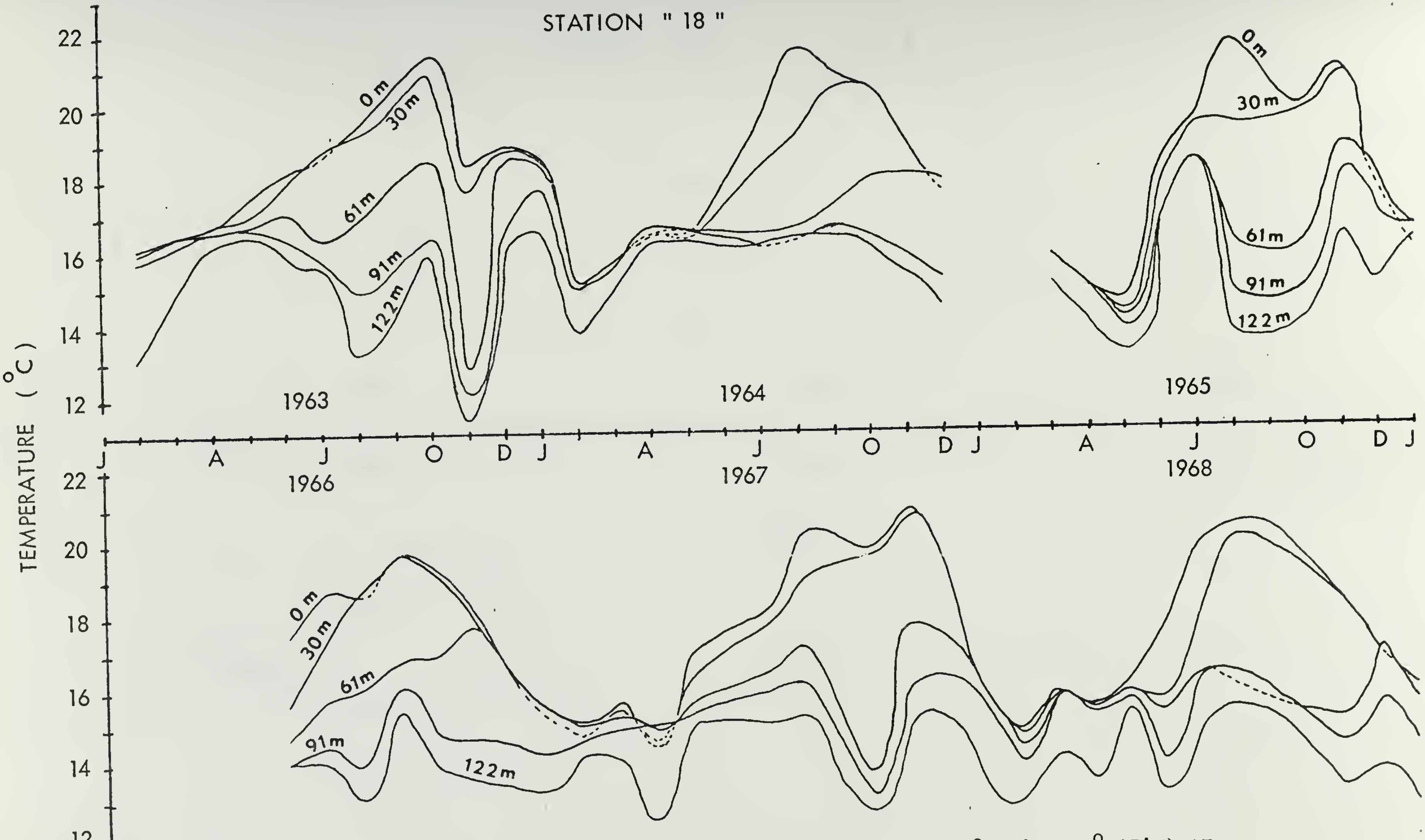


FIGURE 17. OBSERVED ANNUAL TEMPERATURE VARIATIONS FOR STATION 18 (32°-10'N,132°-47'W) AT THE SURFACE, 30, 61, 91, AND 122 METERS.

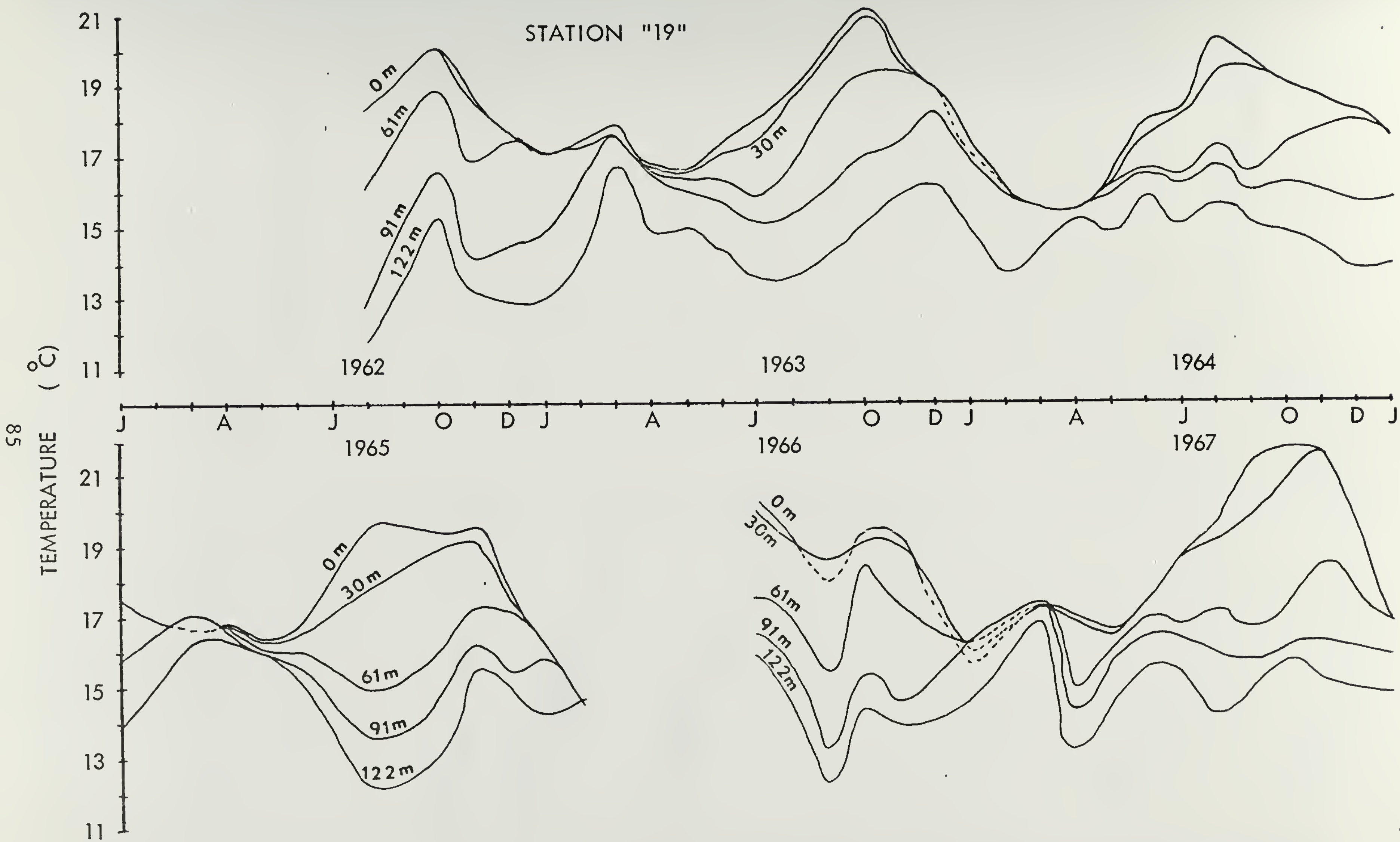


FIGURE 18. OBSERVED ANNUAL TEMPERATURE VARIATIONS FOR STATION 19 (30°-51'N,128°-37'W) AT THE SURFACE, 30, 61, 91, AND 122 METERS.

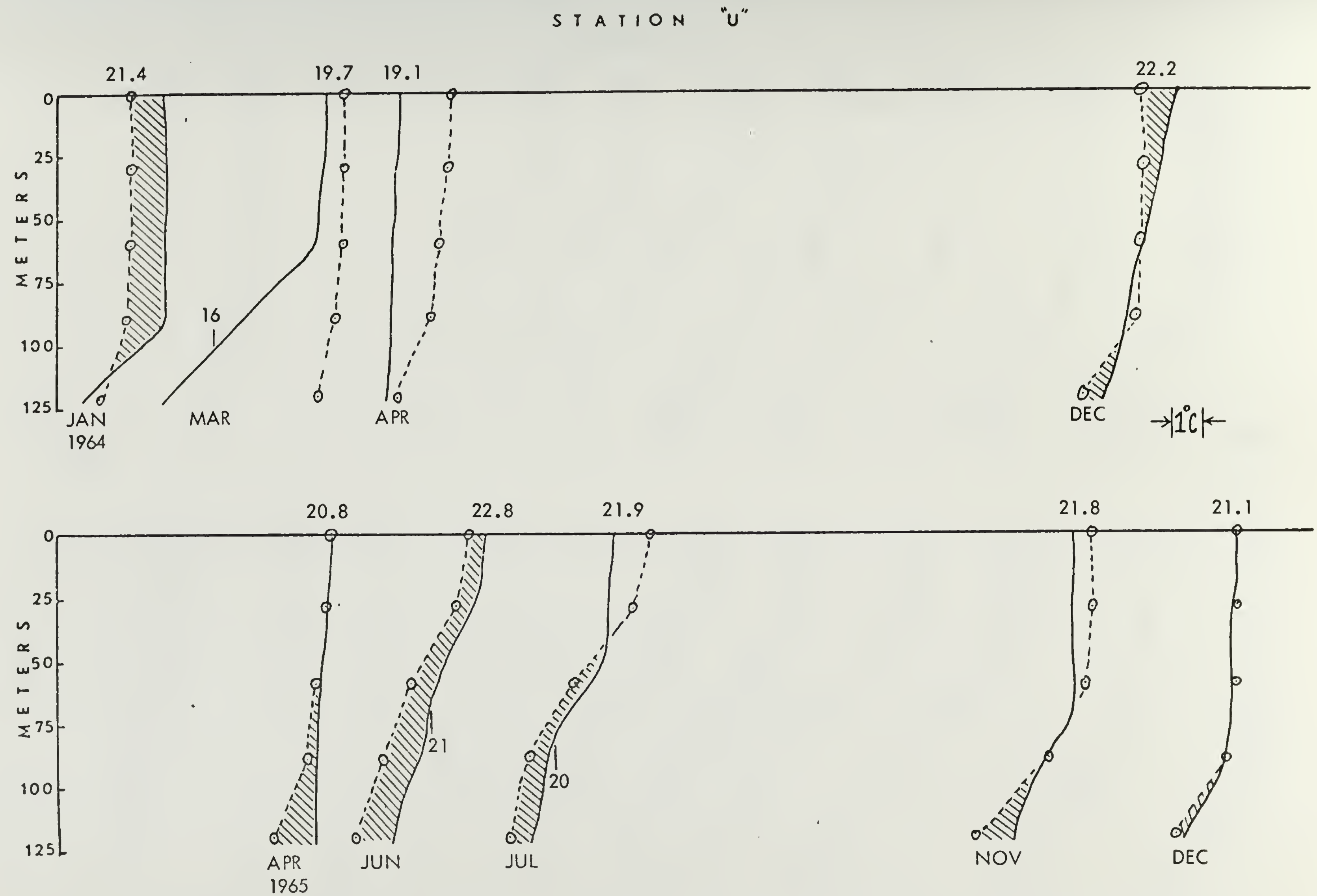


FIGURE 19. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION U. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. (⊙ DENOTES ROBINSON MEAN)

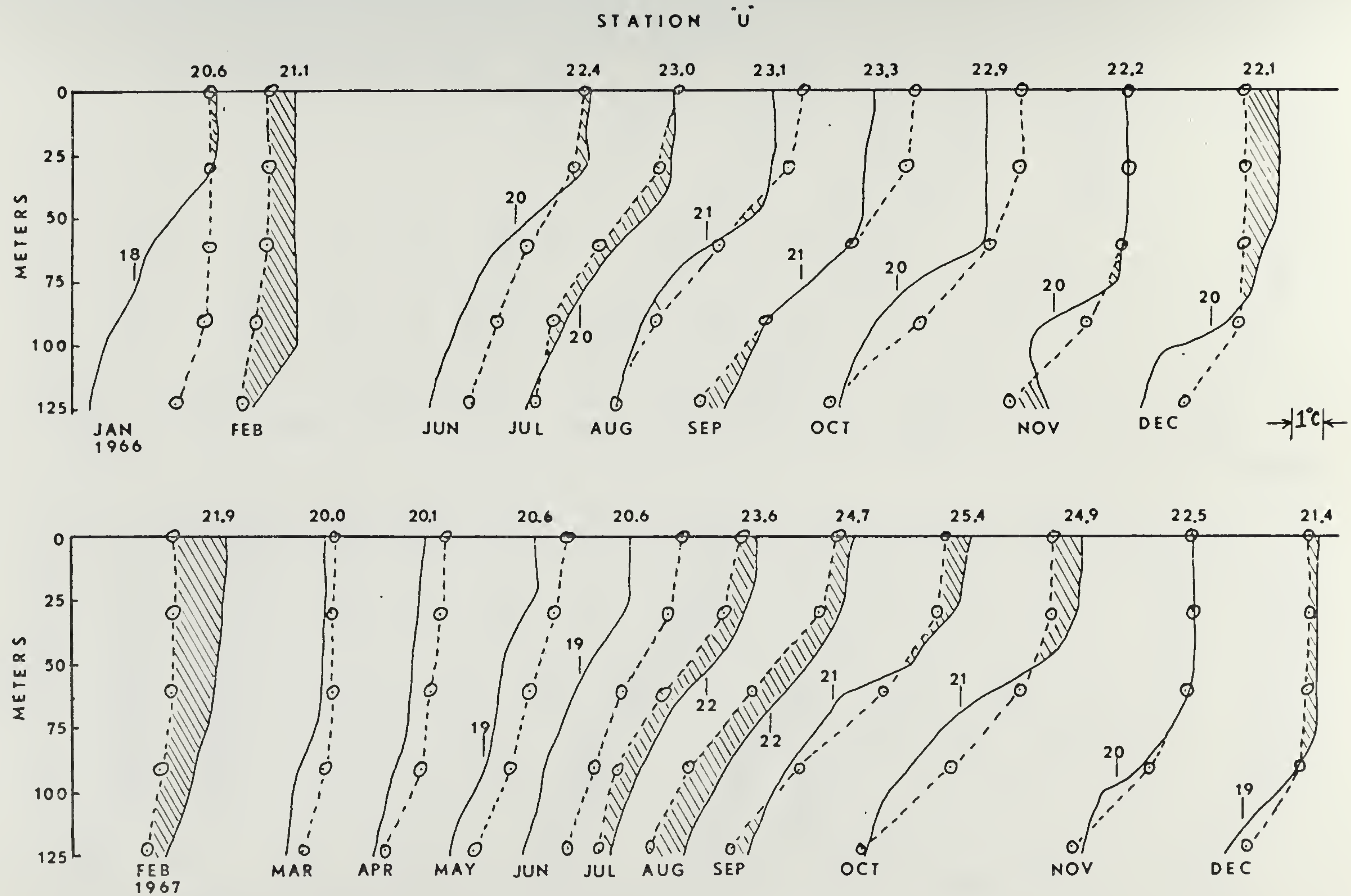


FIGURE 20. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION U. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. (⊙ DENOTES ROBINSON MEAN)

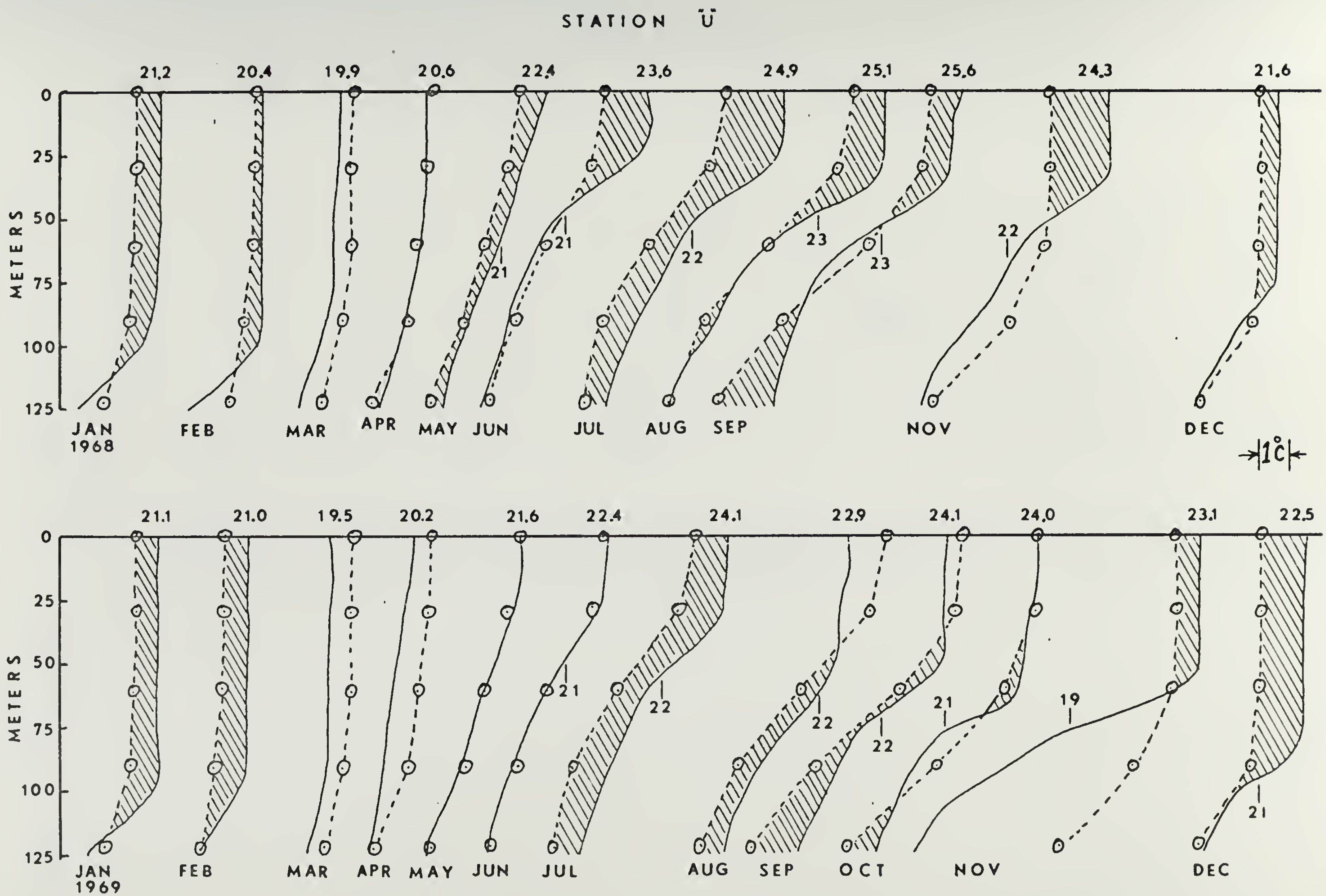


FIGURE 21. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION U. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. (⊙ DENOTES ROBINSON MEAN)

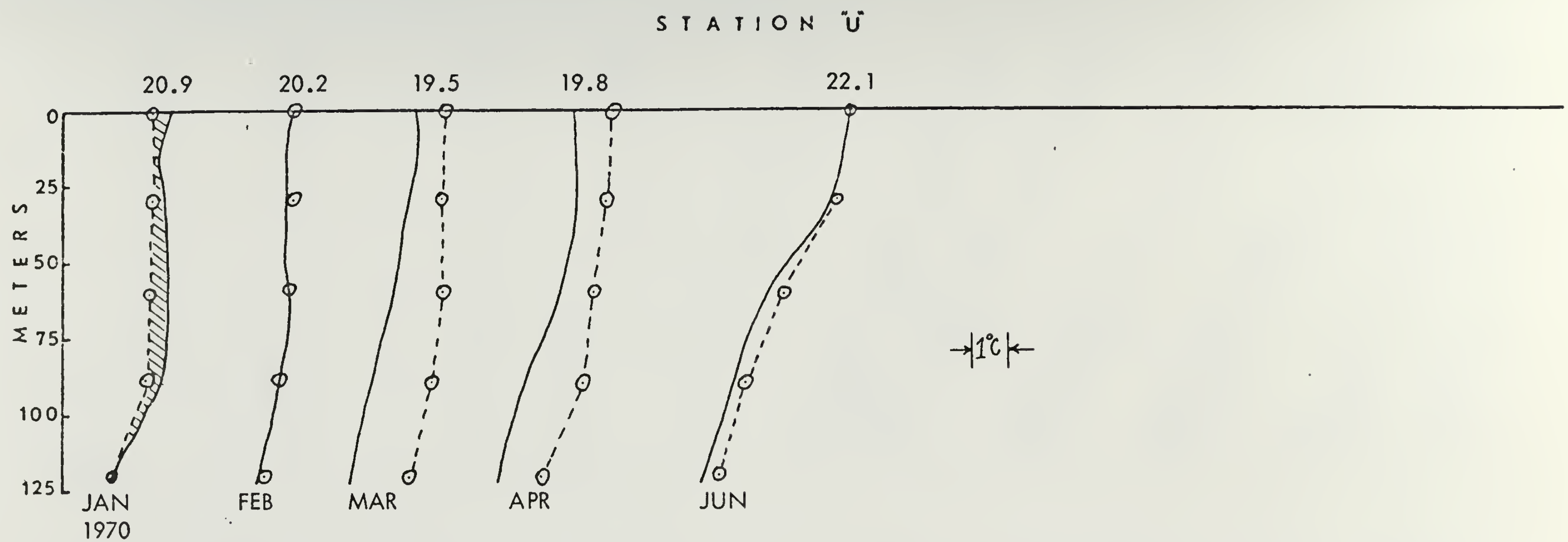
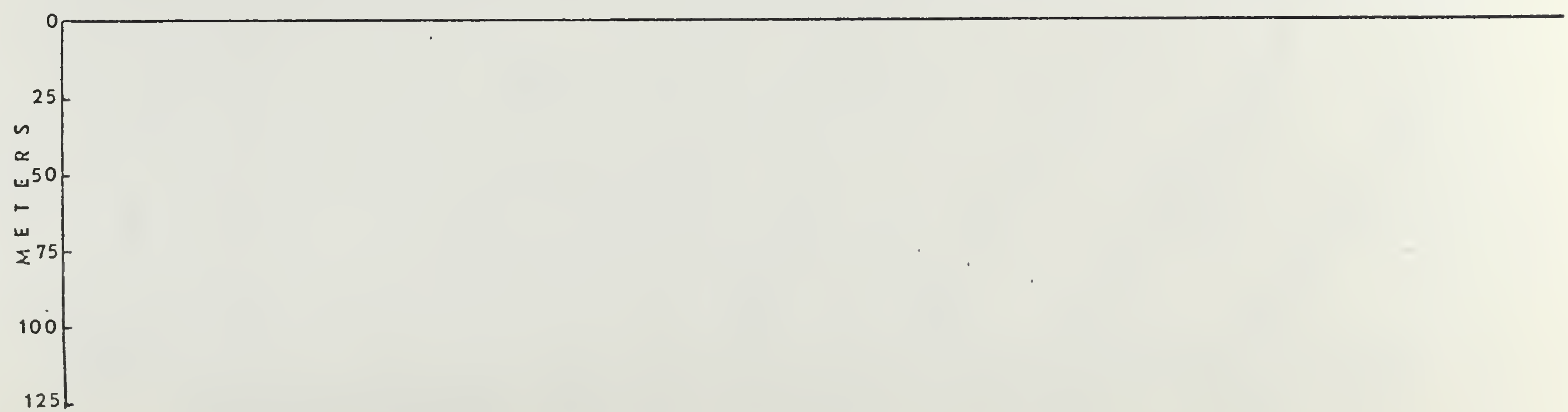


FIGURE 22. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION U. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. (⊙ DENOTES ROBINSON MEAN)



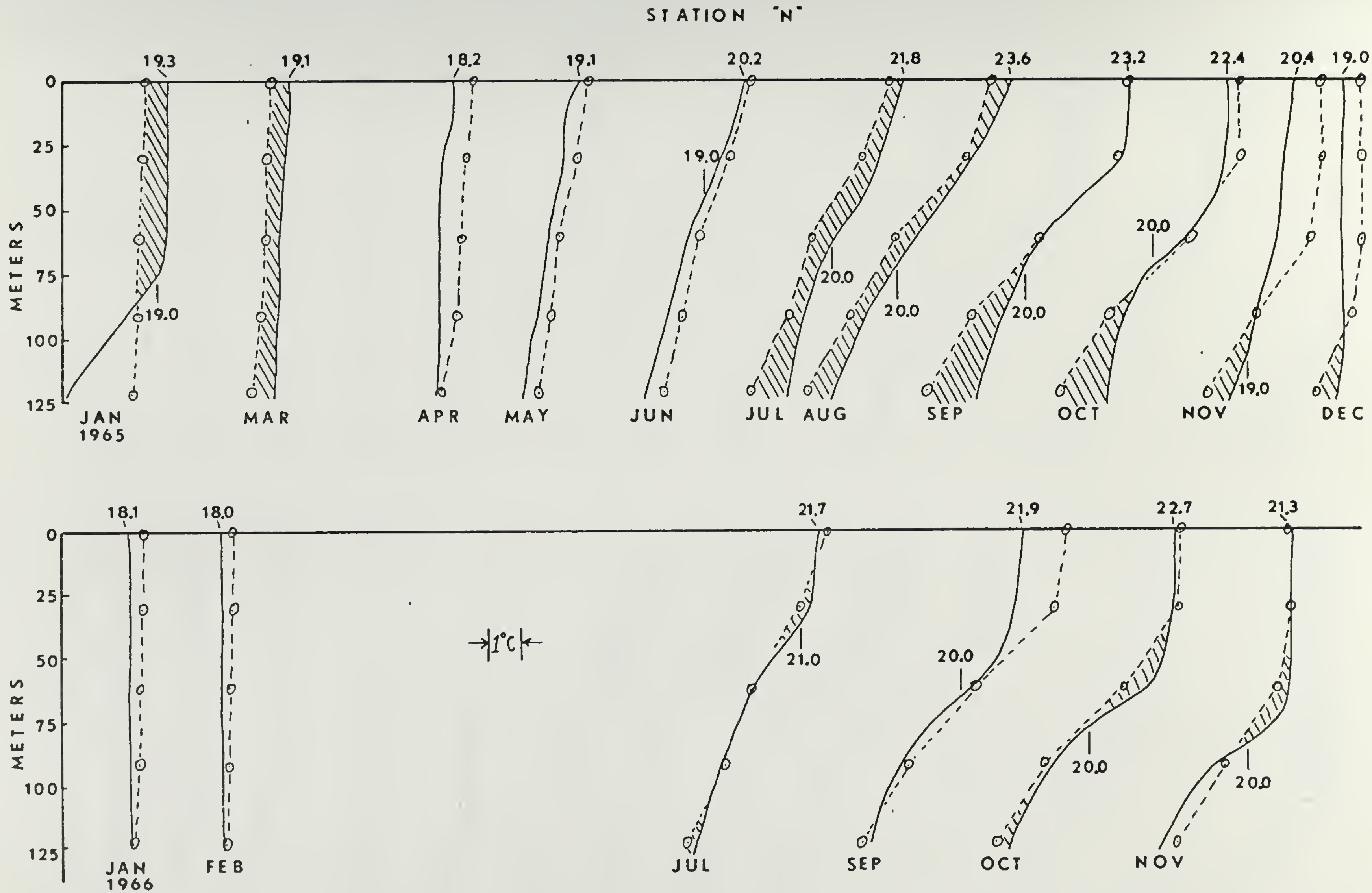


FIGURE 23. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION N. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. 1°C
(⊙ DENOTES ROBINSON MEAN)

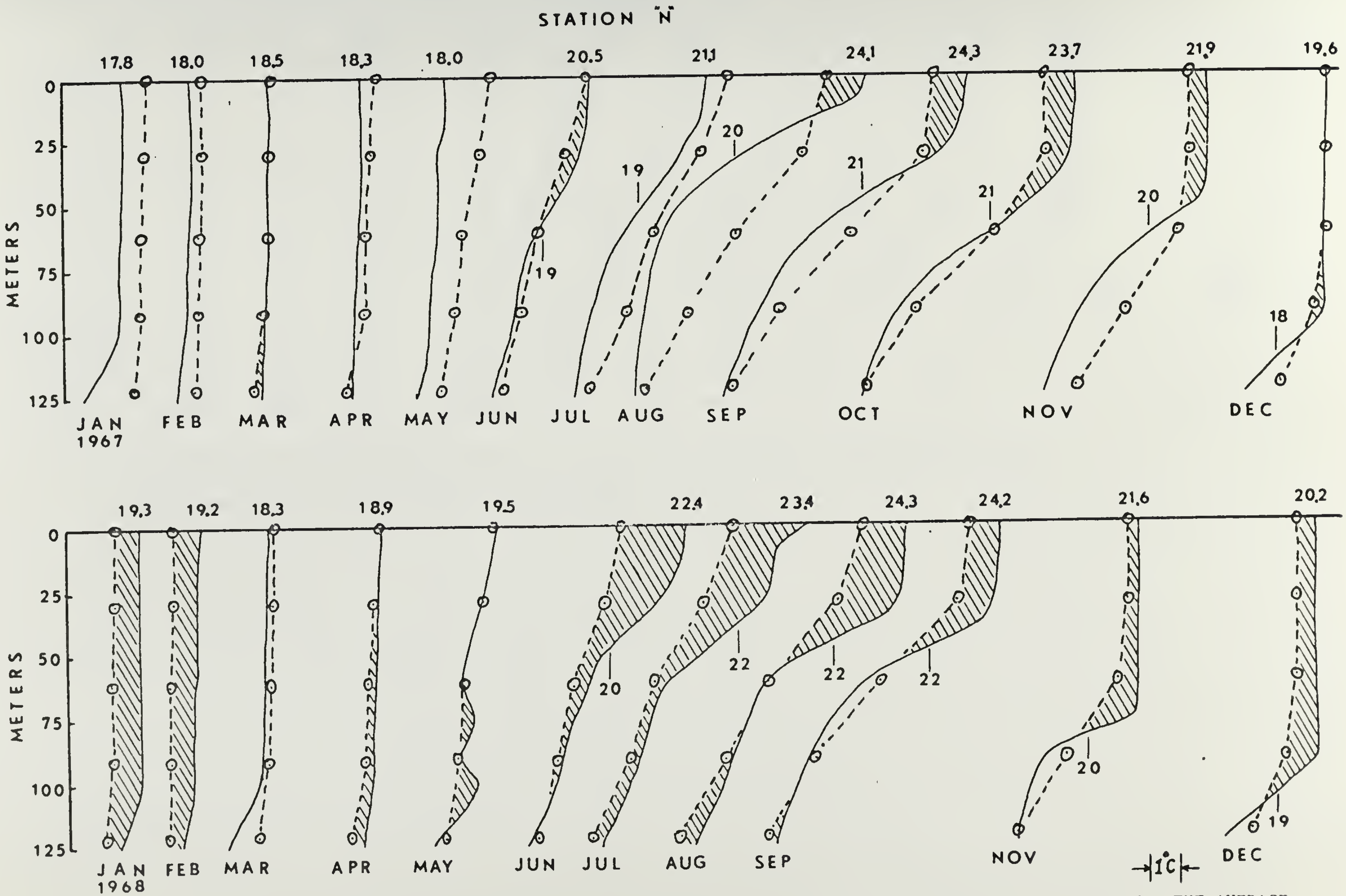


FIGURE 24. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION N. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. (⊙ DENOTES ROBINSON MEAN)

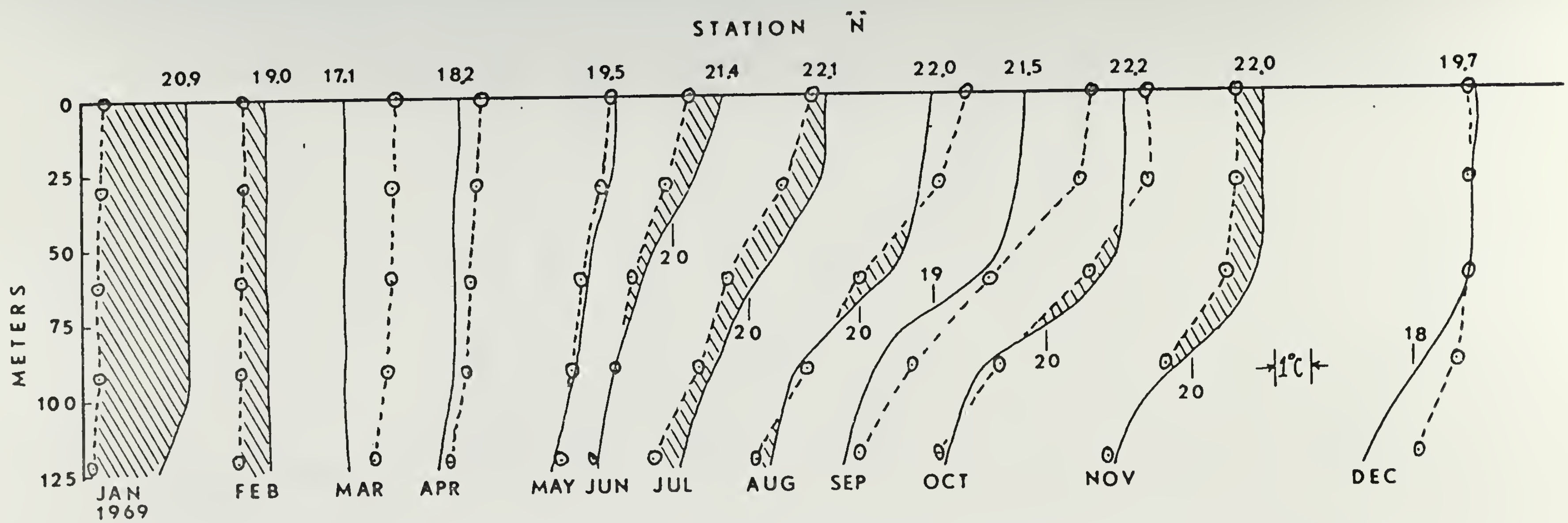


FIGURE 25. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION N. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. (⊙ DENOTES ROBINSON MEAN)

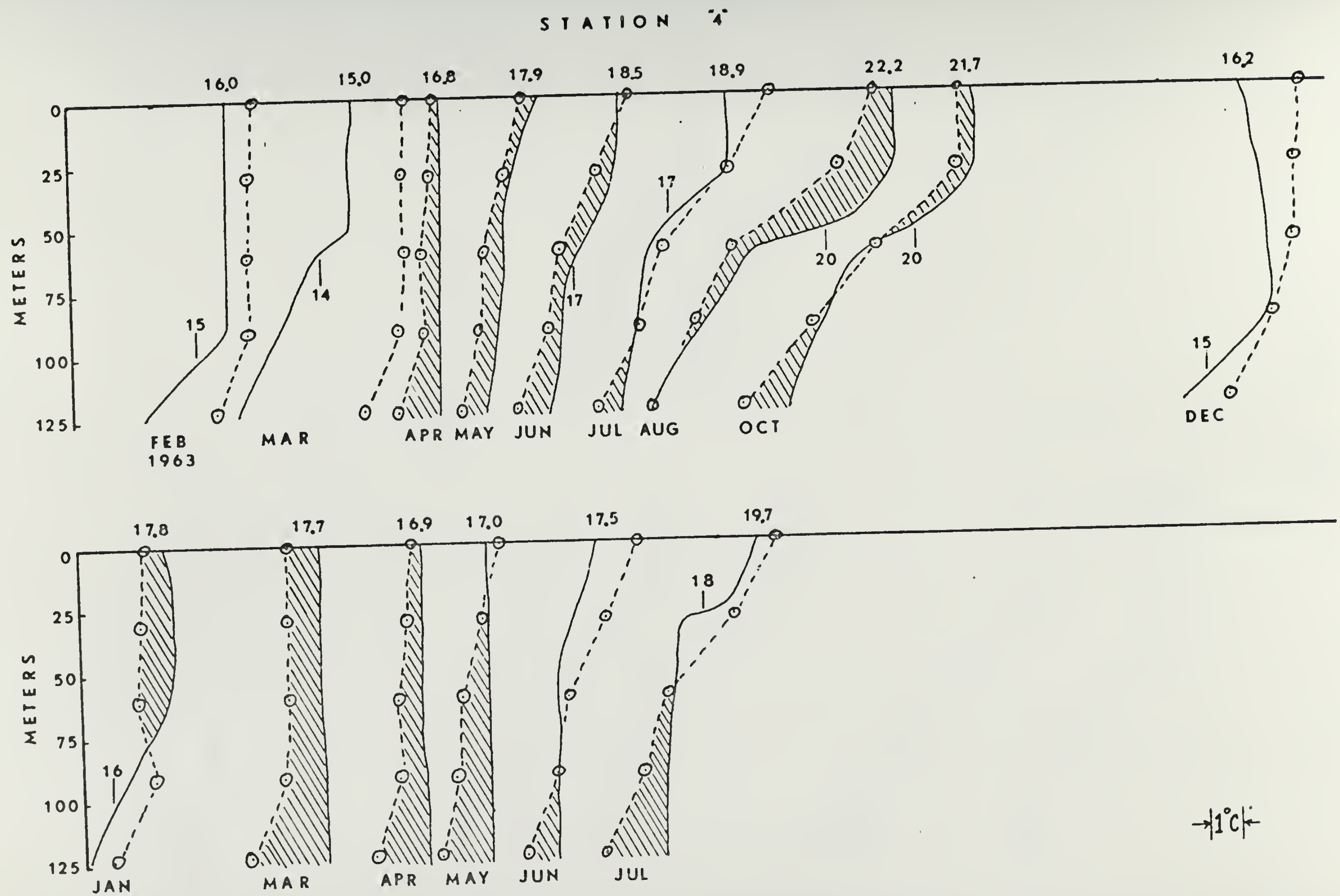


FIGURE 26. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION 4. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. (⊙ DENOTES ROBINSON MEAN)

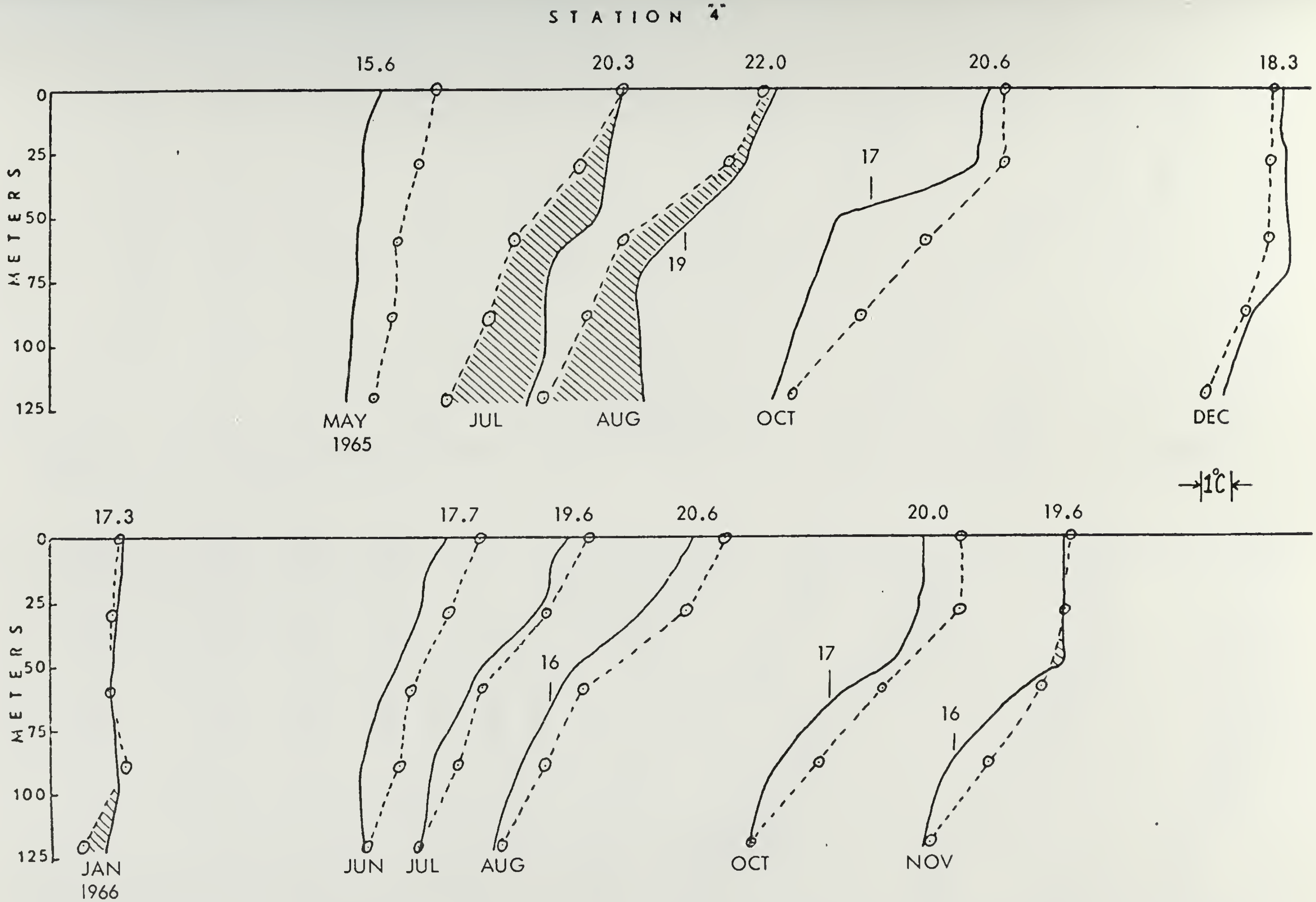


FIGURE 27. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION 4. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. (⊙ DENOTES ROBINSON MEAN)

STATION 4

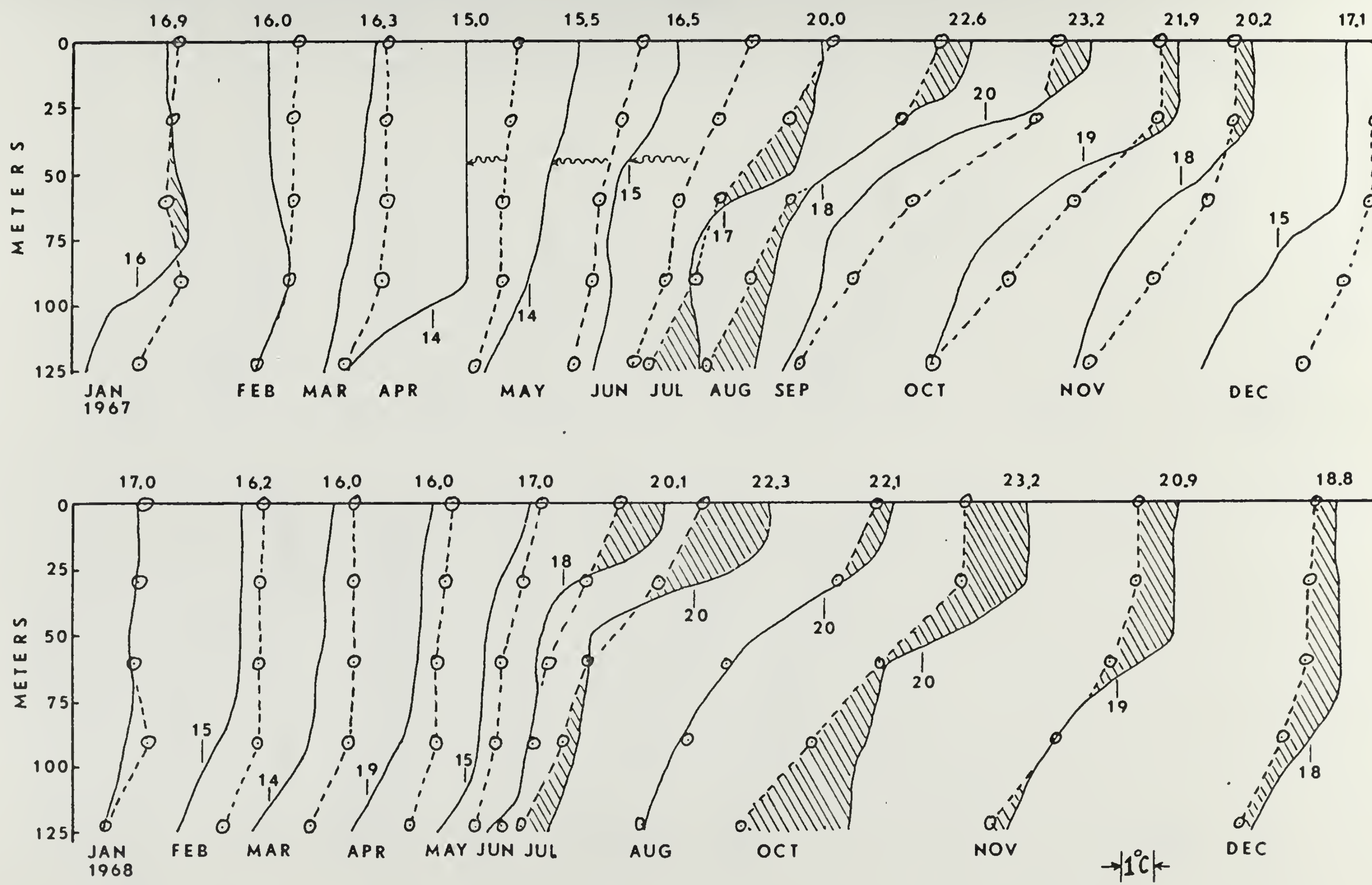


FIGURE 28. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION 4. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. (⊙ DENOTES ROBINSON MEAN)

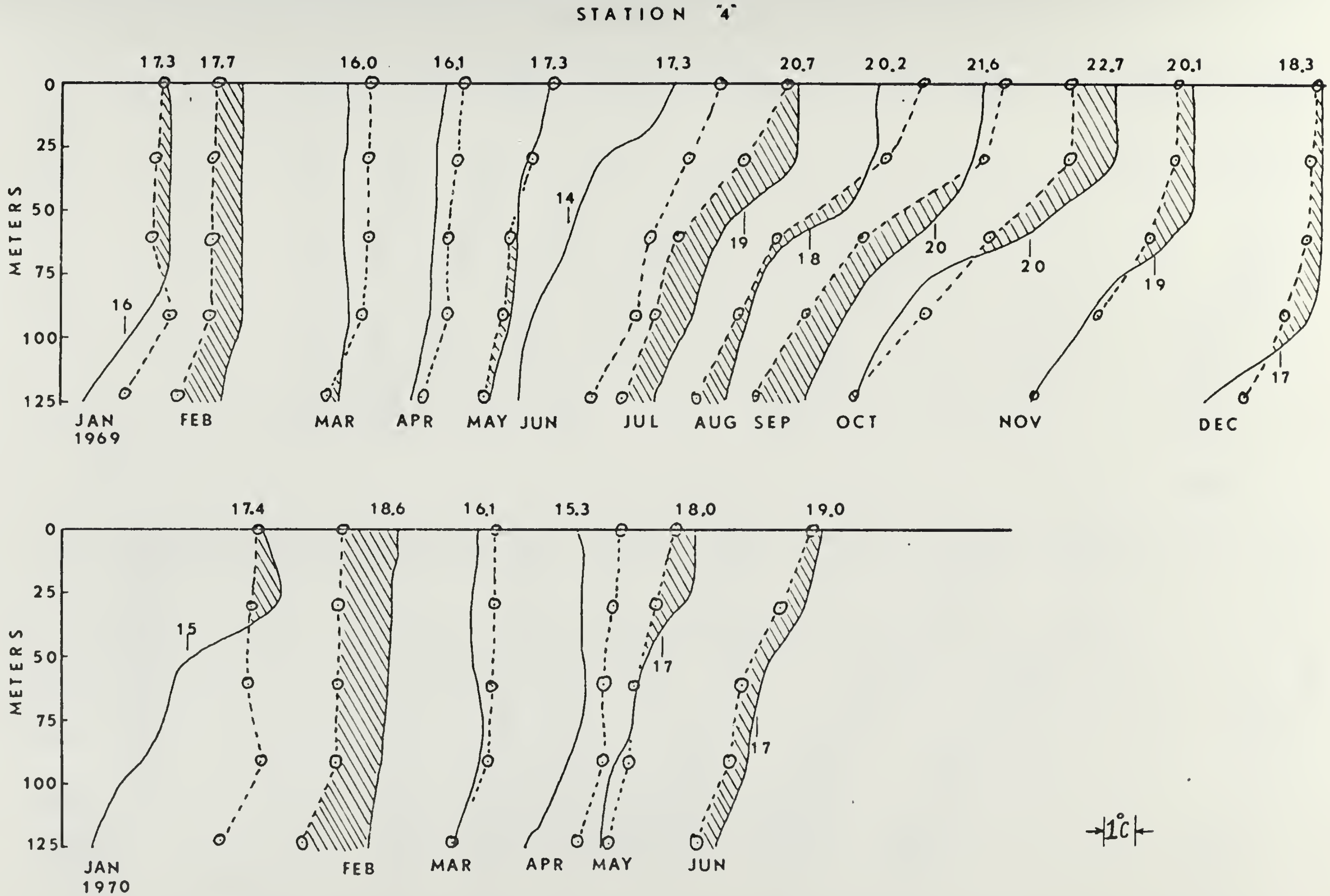


FIGURE 29. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION 4. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. (⊙ DENOTES ROBINSON MEAN)

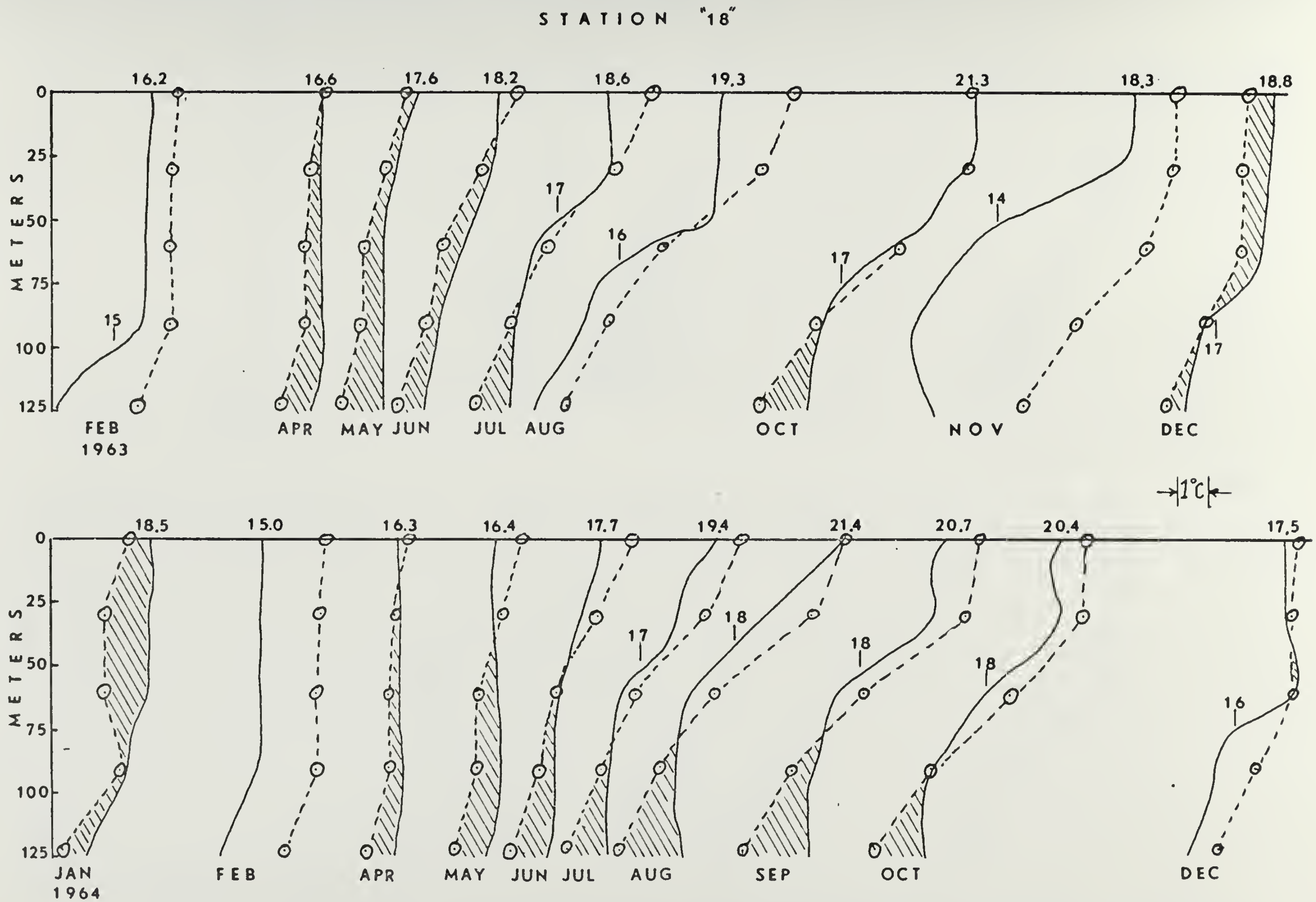


FIGURE 30. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION 18. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED INDICATE WARMER THAN NORMAL WATER. (⊙ DENOTES ROBINSON MEAN)

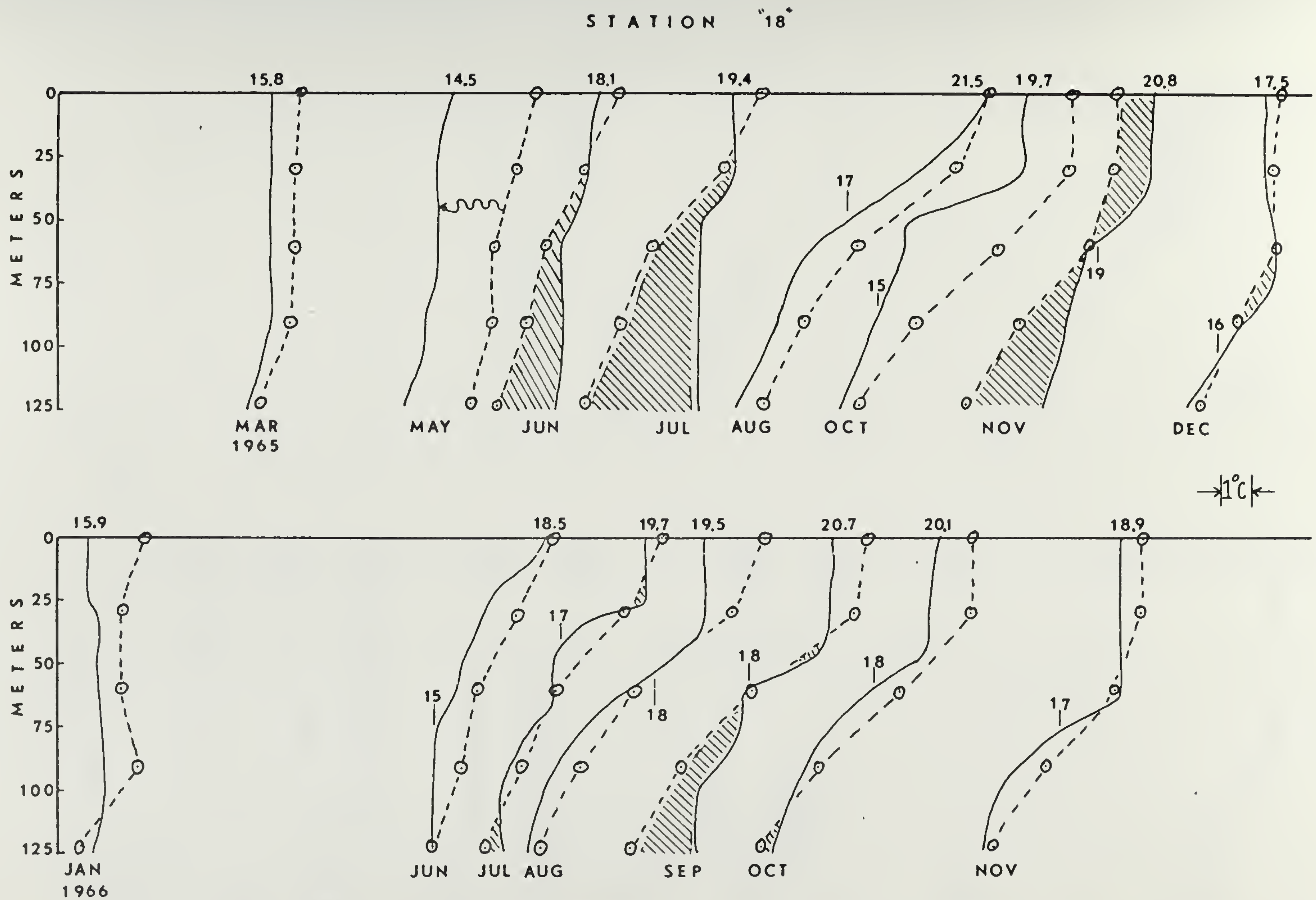


FIGURE 31. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION 18. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. (⊙ DENOTES ROBINSON MEAN)

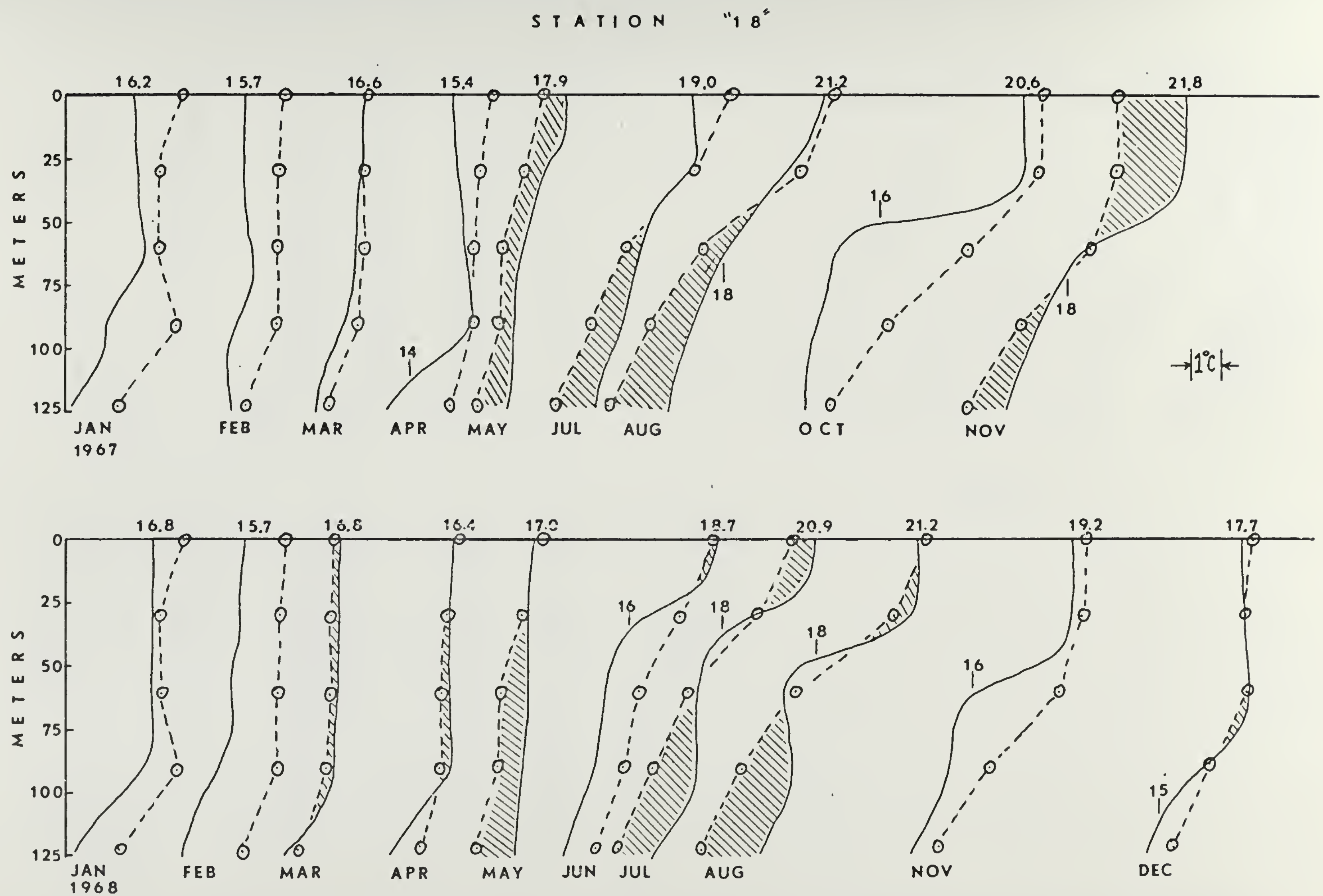


FIGURE 32. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION 18. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. (⊙ DENOTES ROBINSON MEAN)

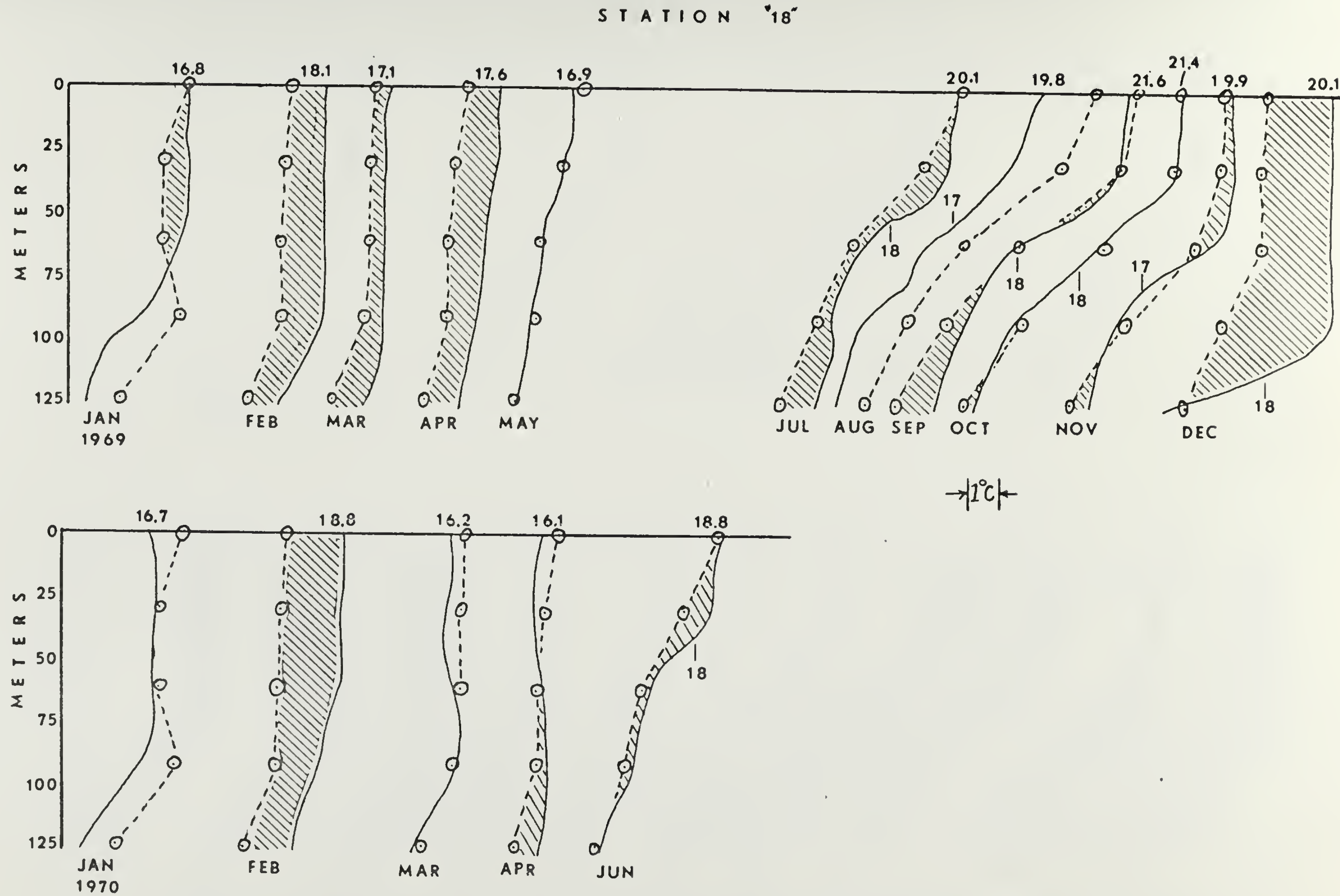


FIGURE 33. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION 18. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. (⊙ DENOTES ROBINSON MEAN)

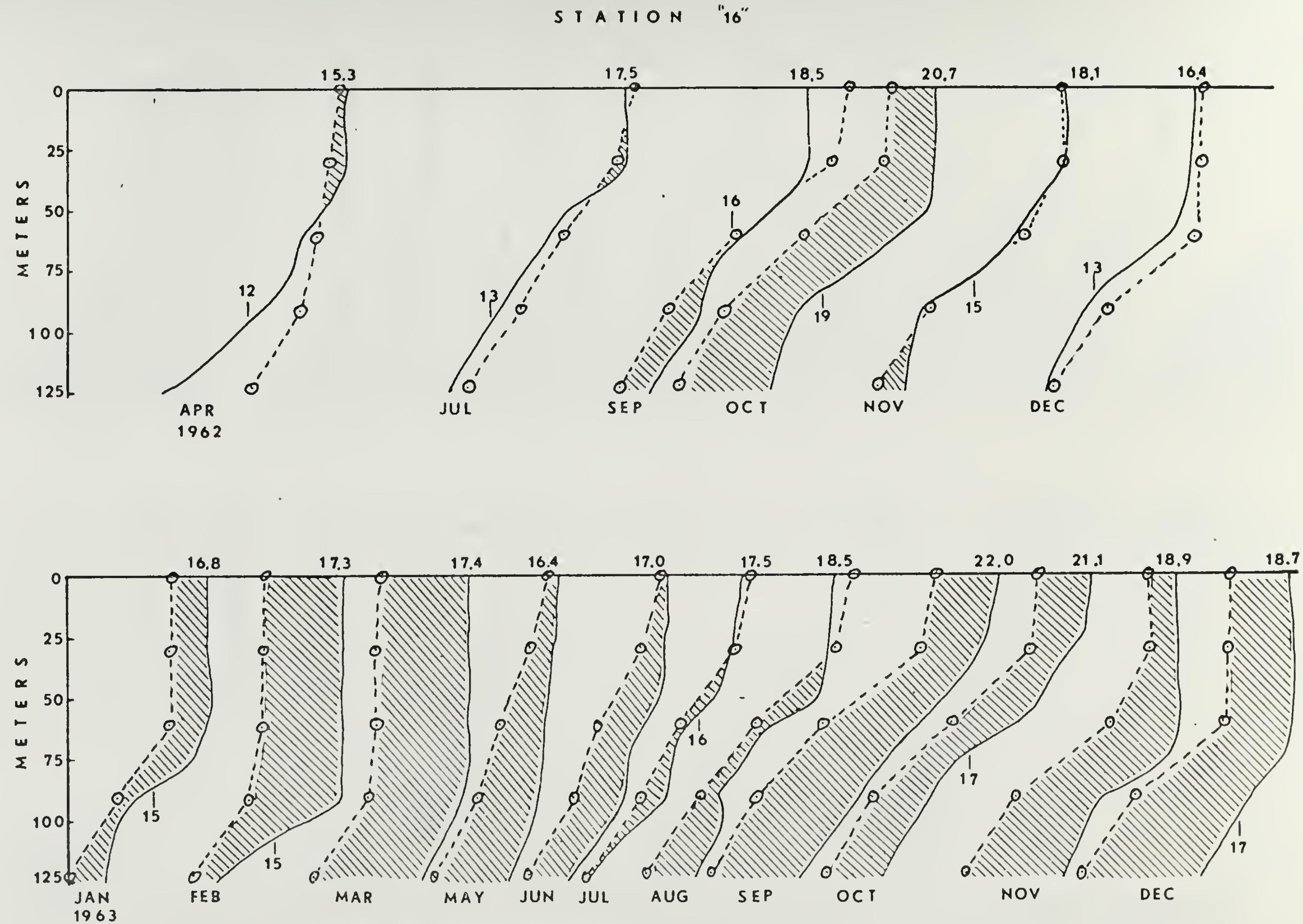


FIGURE 34. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION 16. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. (⊙ DENOTES ROBINSON MEAN)

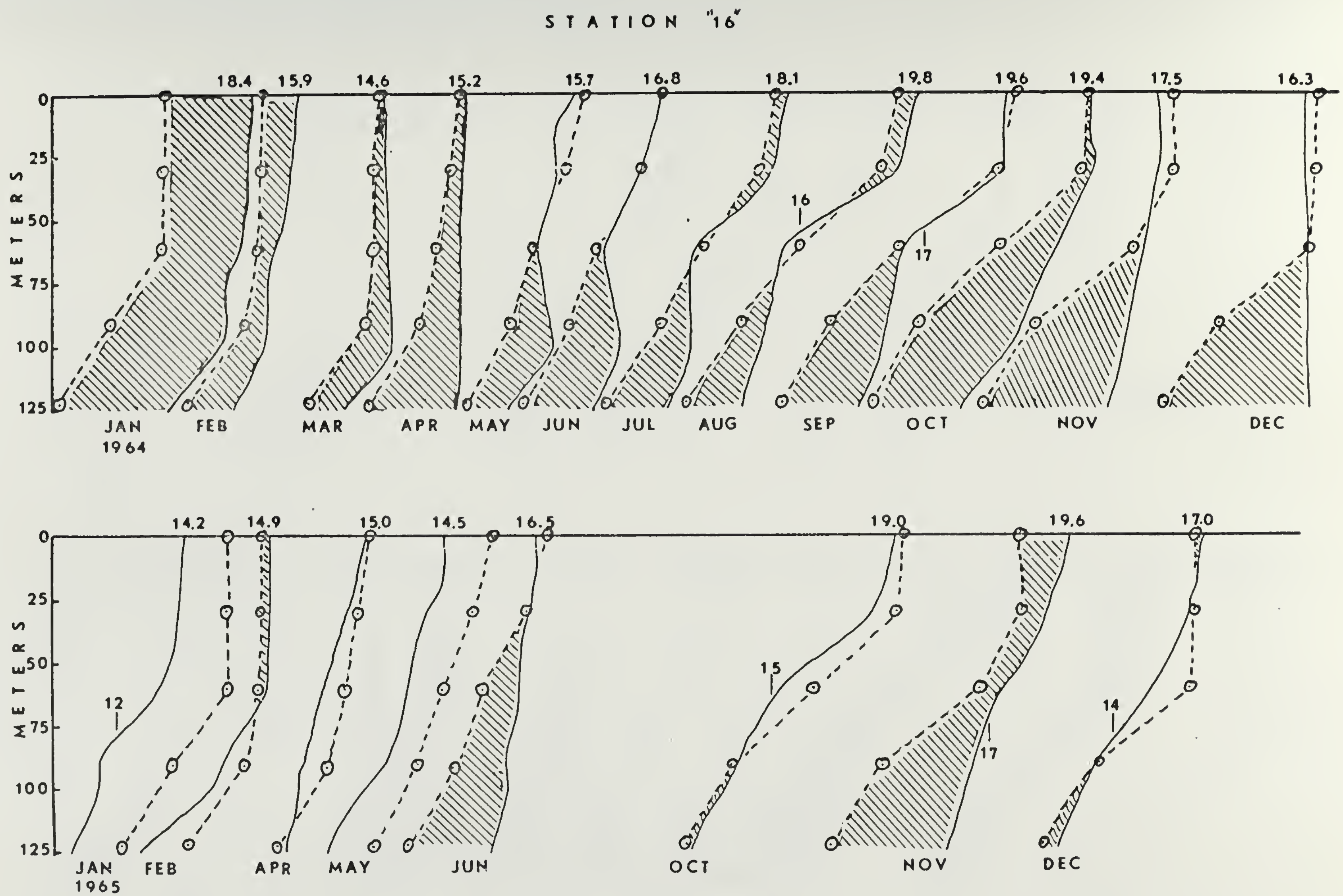


FIGURE 35. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION 16. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. (⊙ DENOTES ROBINSON MEAN)

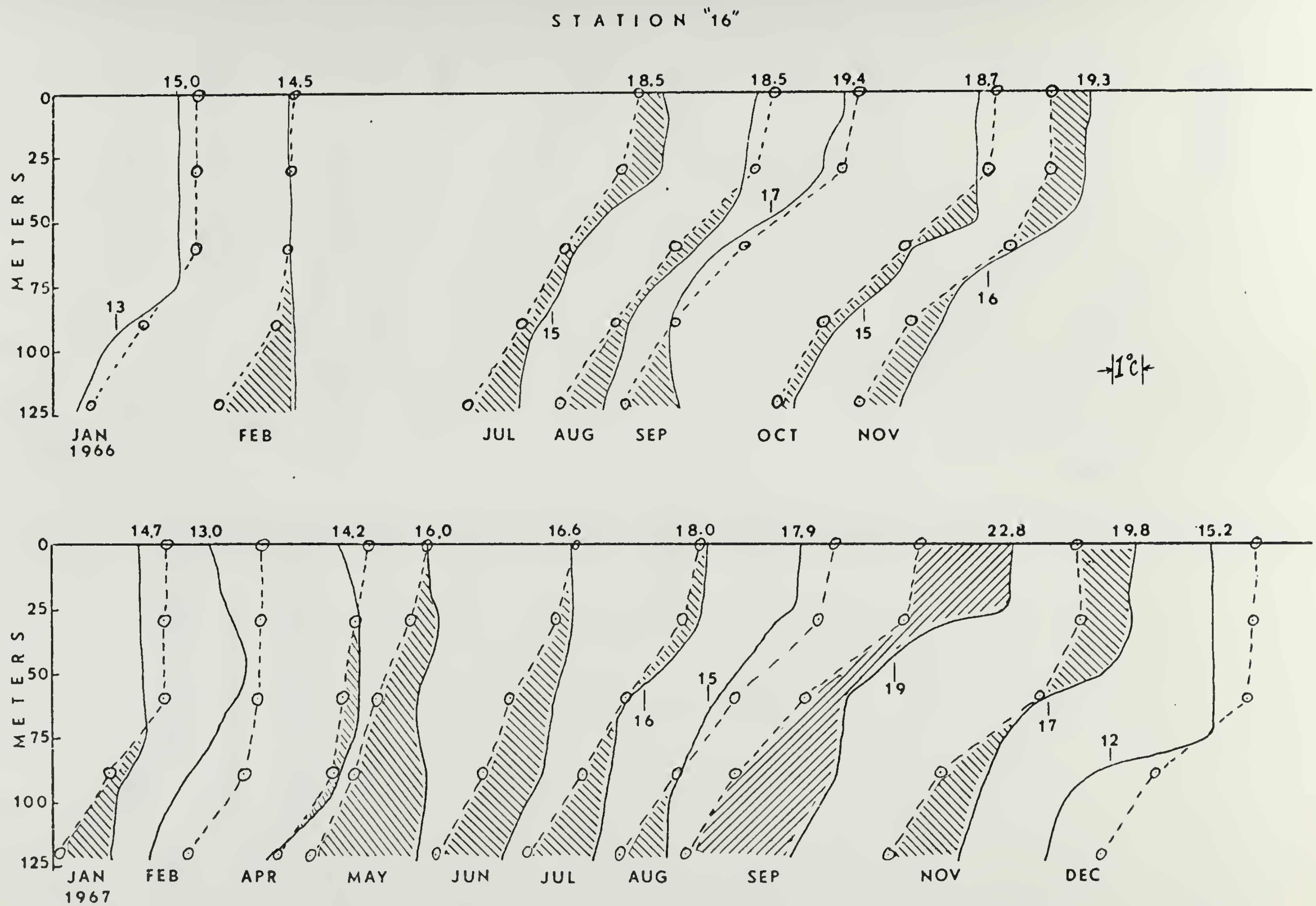


FIGURE 36. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION 16. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. (⊙ DENOTES ROBINSON MEAN)

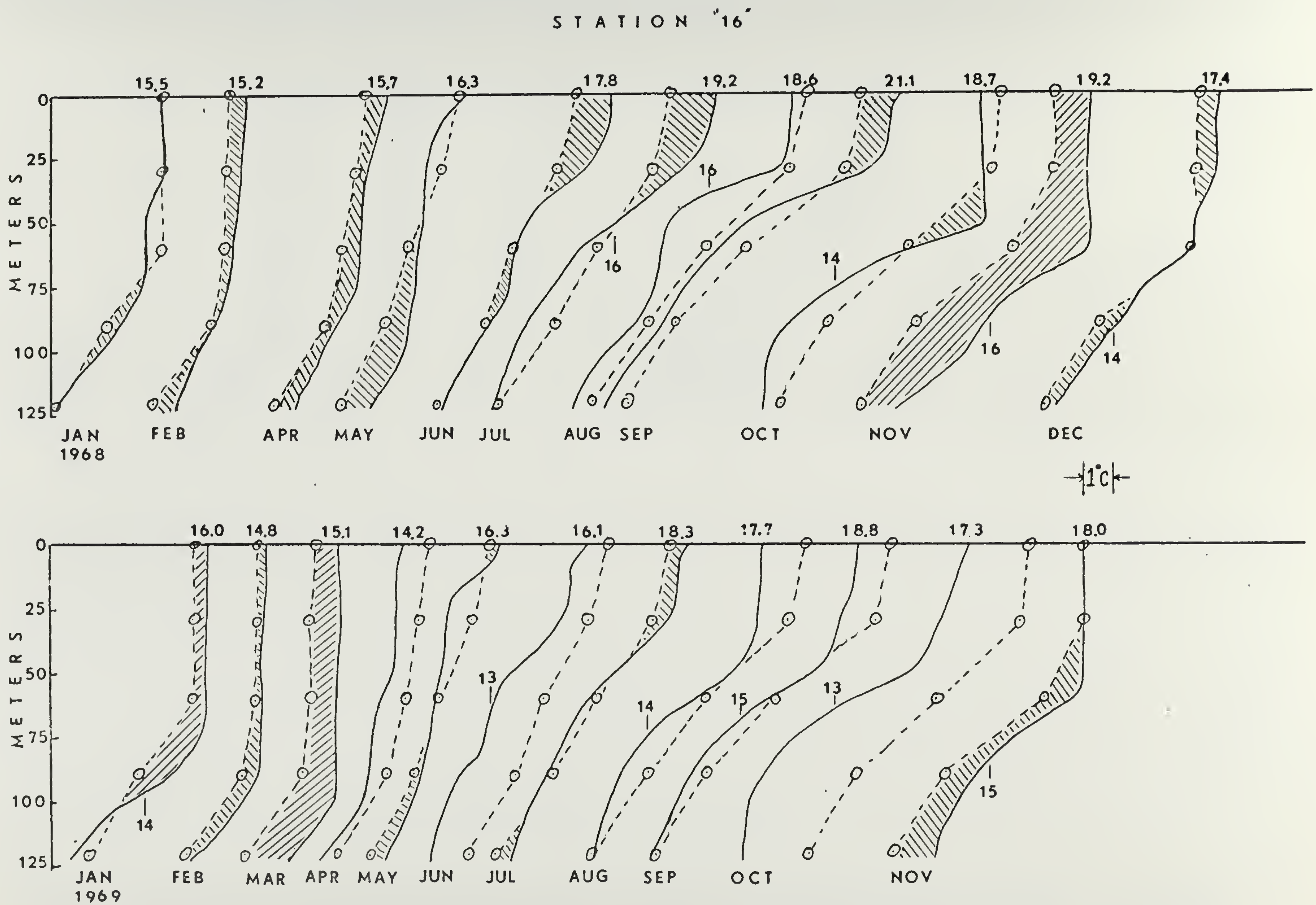


FIGURE 37. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION 16. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. (⊘ DENOTES ROBINSON MEAN)

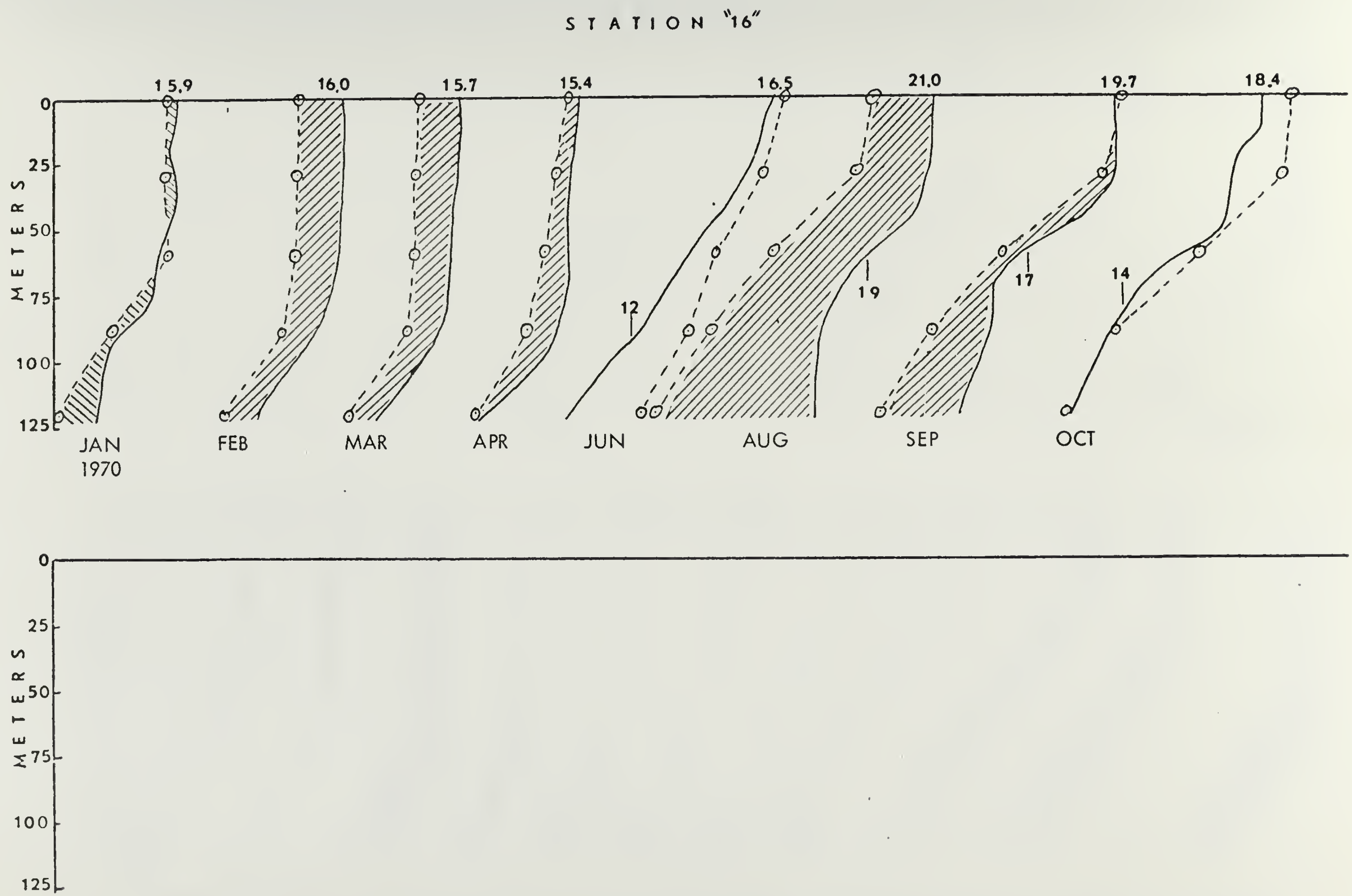


FIGURE 38. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION 16. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. (⊙ DENOTES ROBINSON MEAN)

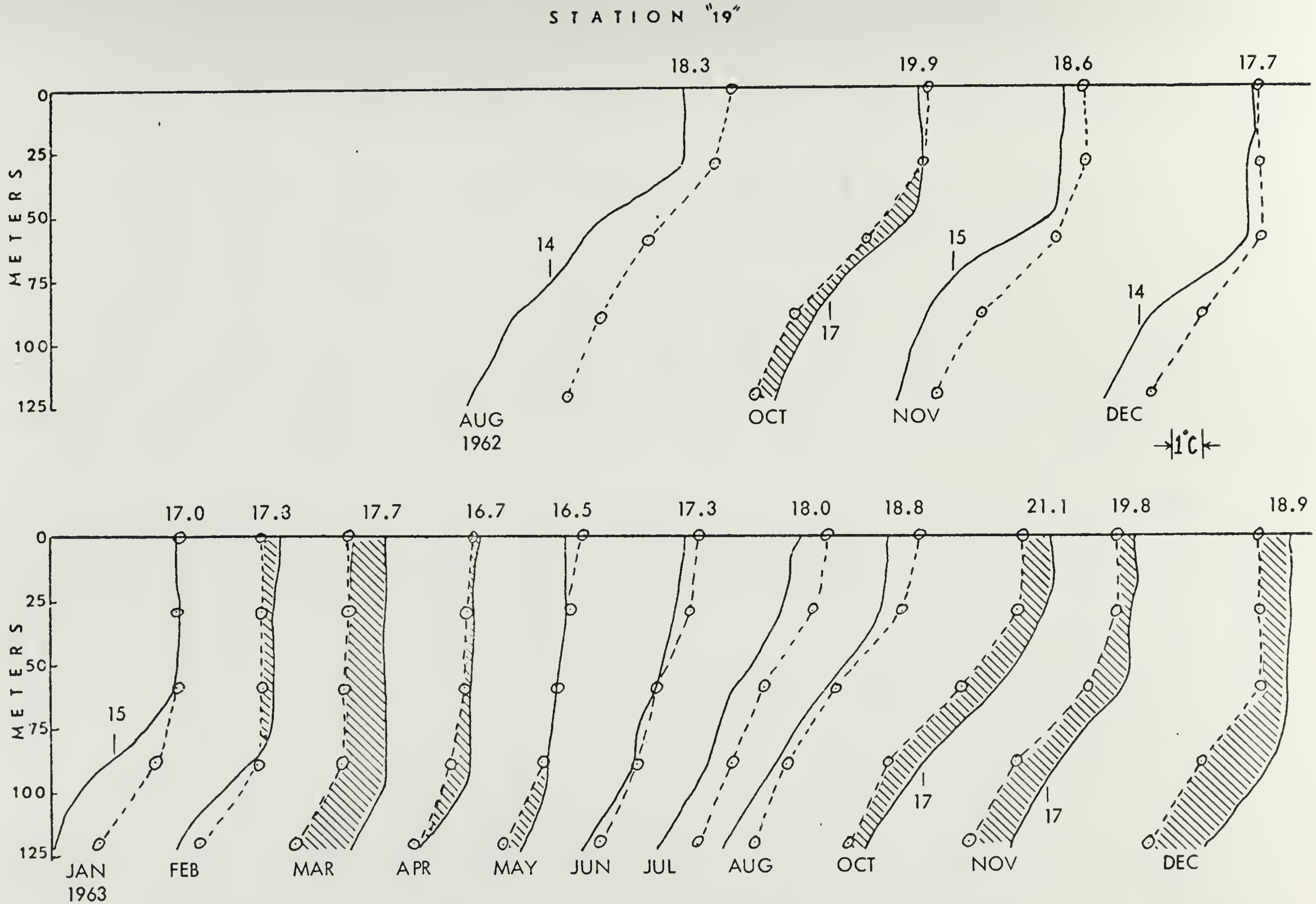


FIGURE 39. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION 19. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. (⊙ DENOTES ROBINSON MEAN)

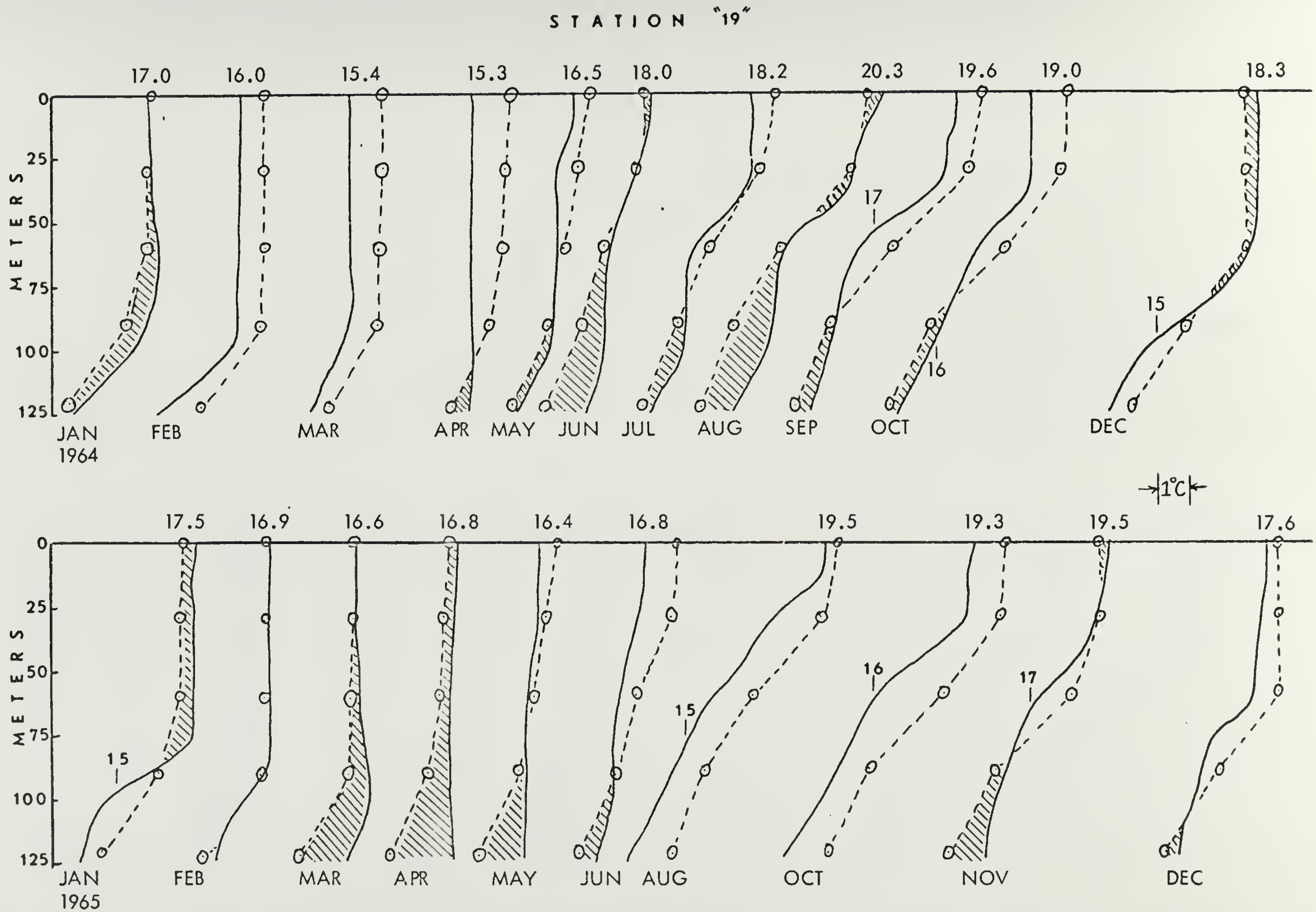


FIGURE 40. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION 19. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. (O DENOTES ROBINSON MEAN)

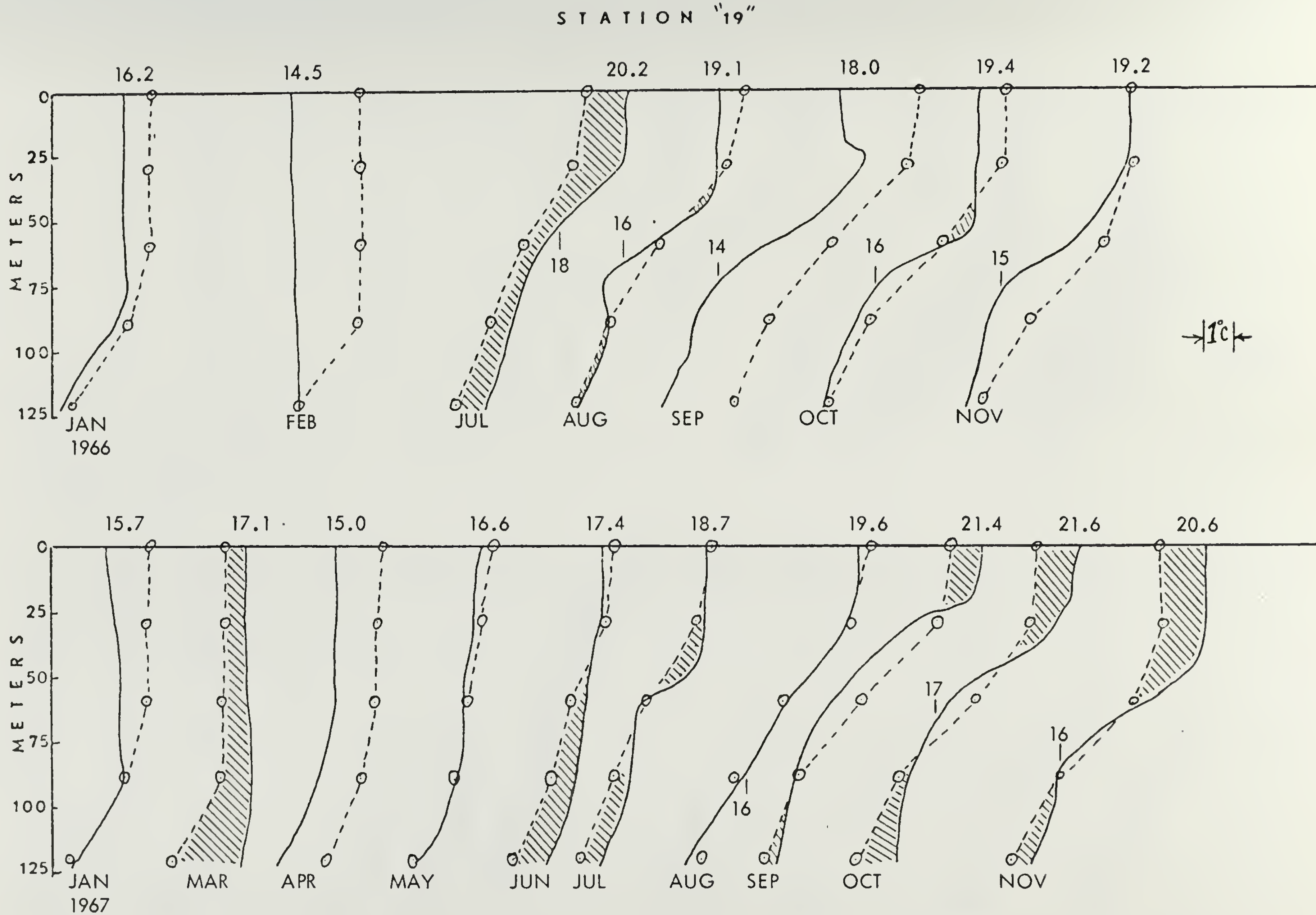


FIGURE 41. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION 19. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. (O DENOTES ROBINSON MEAN)

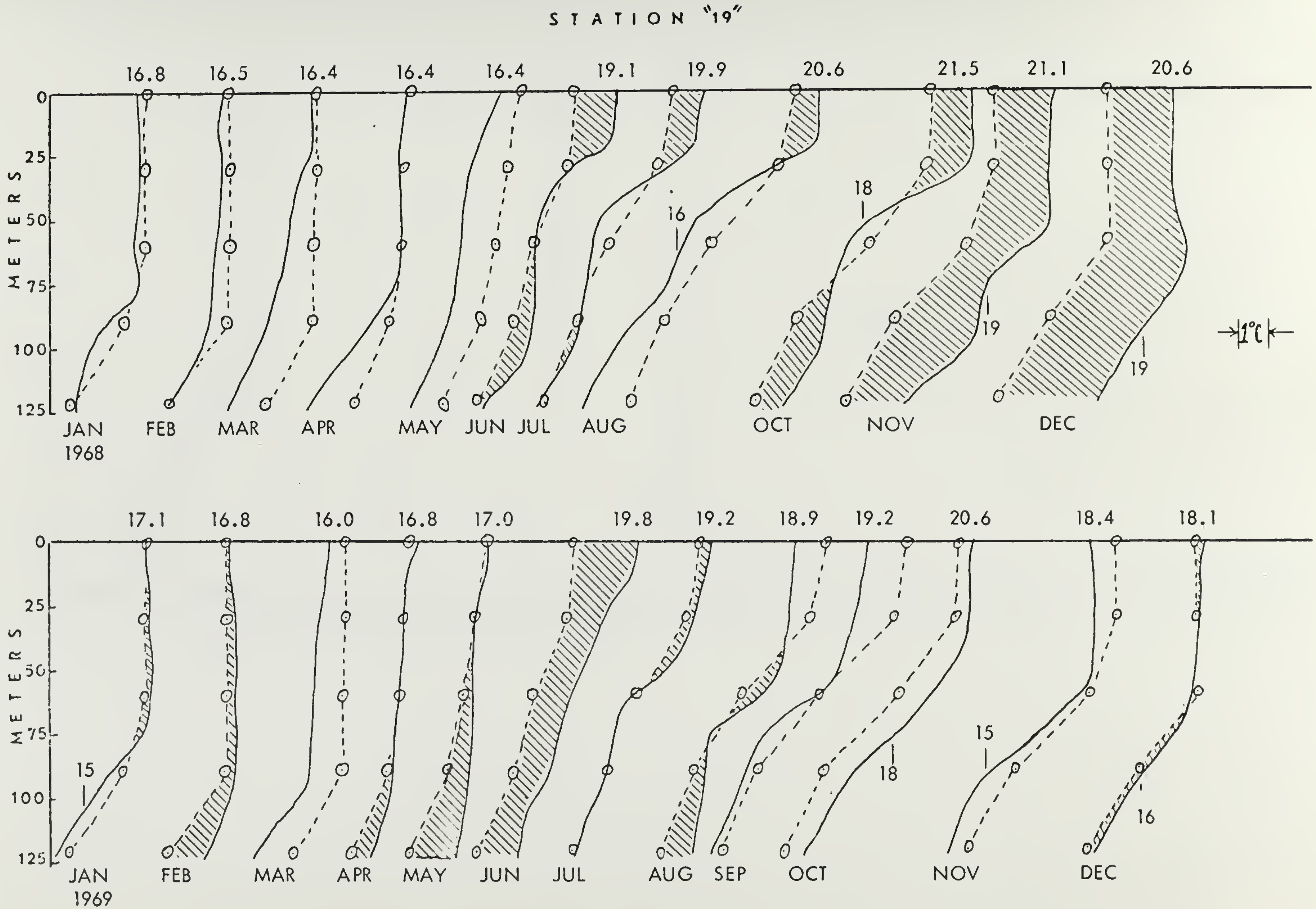


FIGURE 42. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION 19. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. (⊙ DENOTES ROBINSON MEAN)

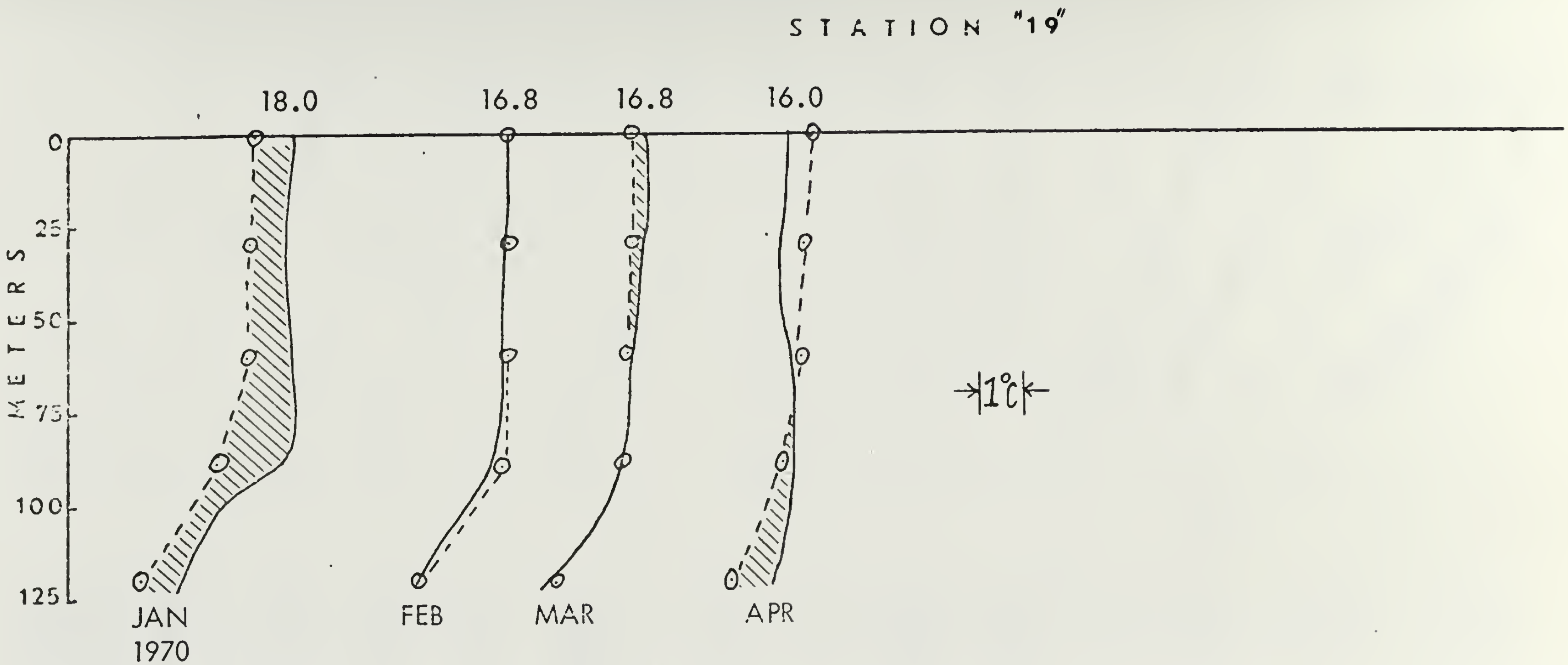


FIGURE 43. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION 19. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. (⊙ DENOTES ROBINSON MEAN)

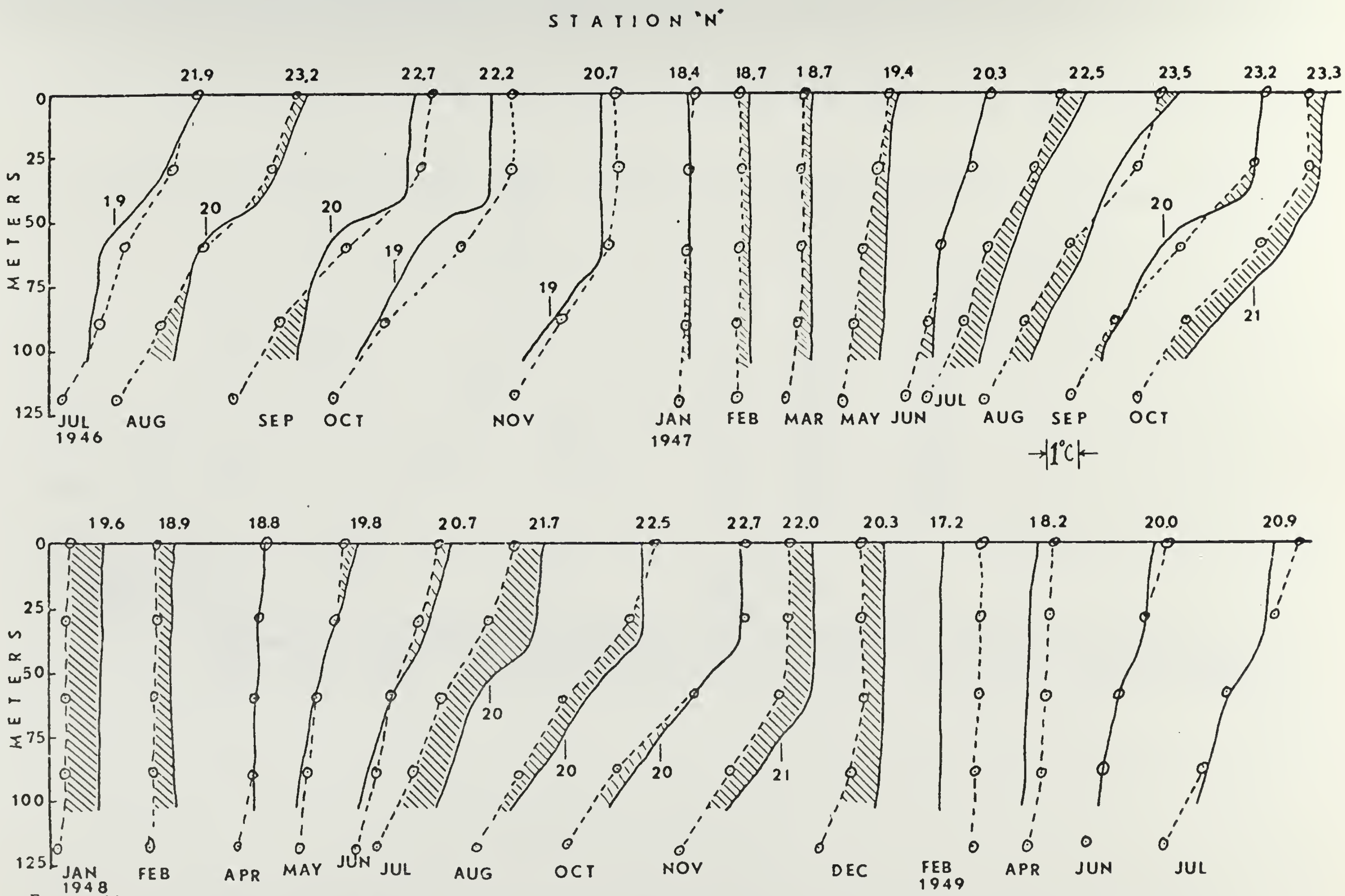


FIGURE 44. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION N. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. (⊙ DENOTES ROBINSON MEAN)

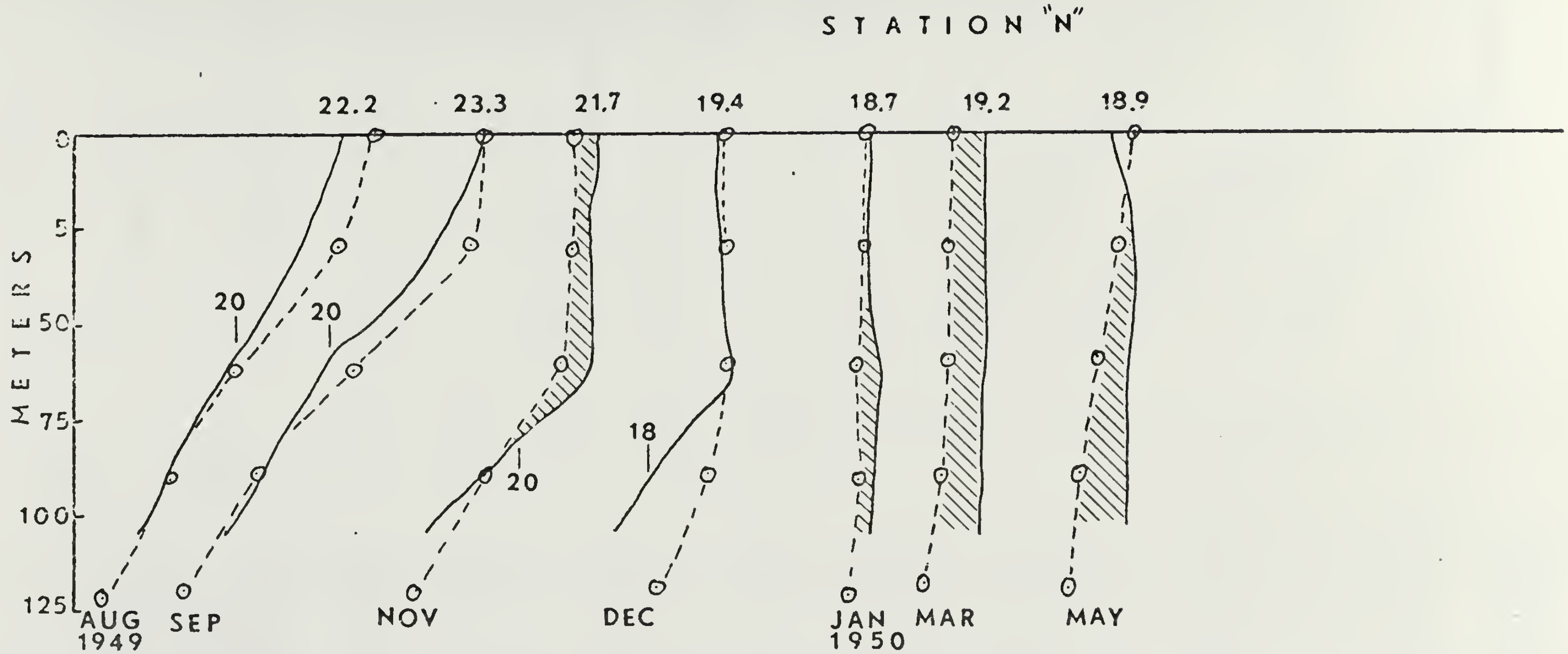


FIGURE 45. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATION N. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. (⊙ DENOTES ROBINSON MEAN)

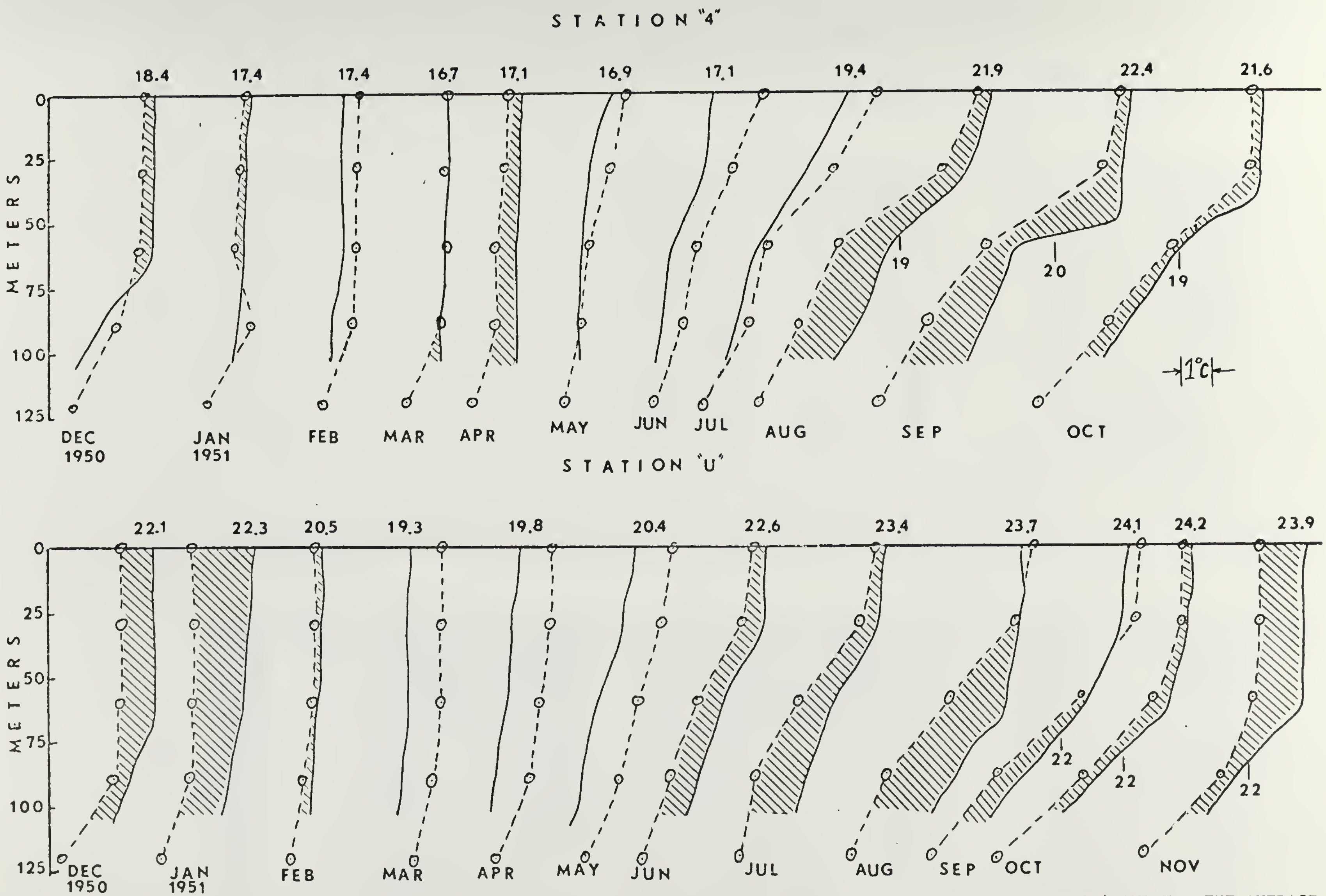


FIGURE 46. COMPARISON OF COMPUTED MEAN MONTHLY BT FOR SPECIFIC YEARS WITH LONG TERM MEAN FOR STATIONS 4 AND U. THE AVERAGE OBSERVED SST IS ALSO PLOTTED. SHADED AREAS INDICATE WARMER THAN NORMAL WATER. (⊙ DENOTES ROBINSON MEAN)

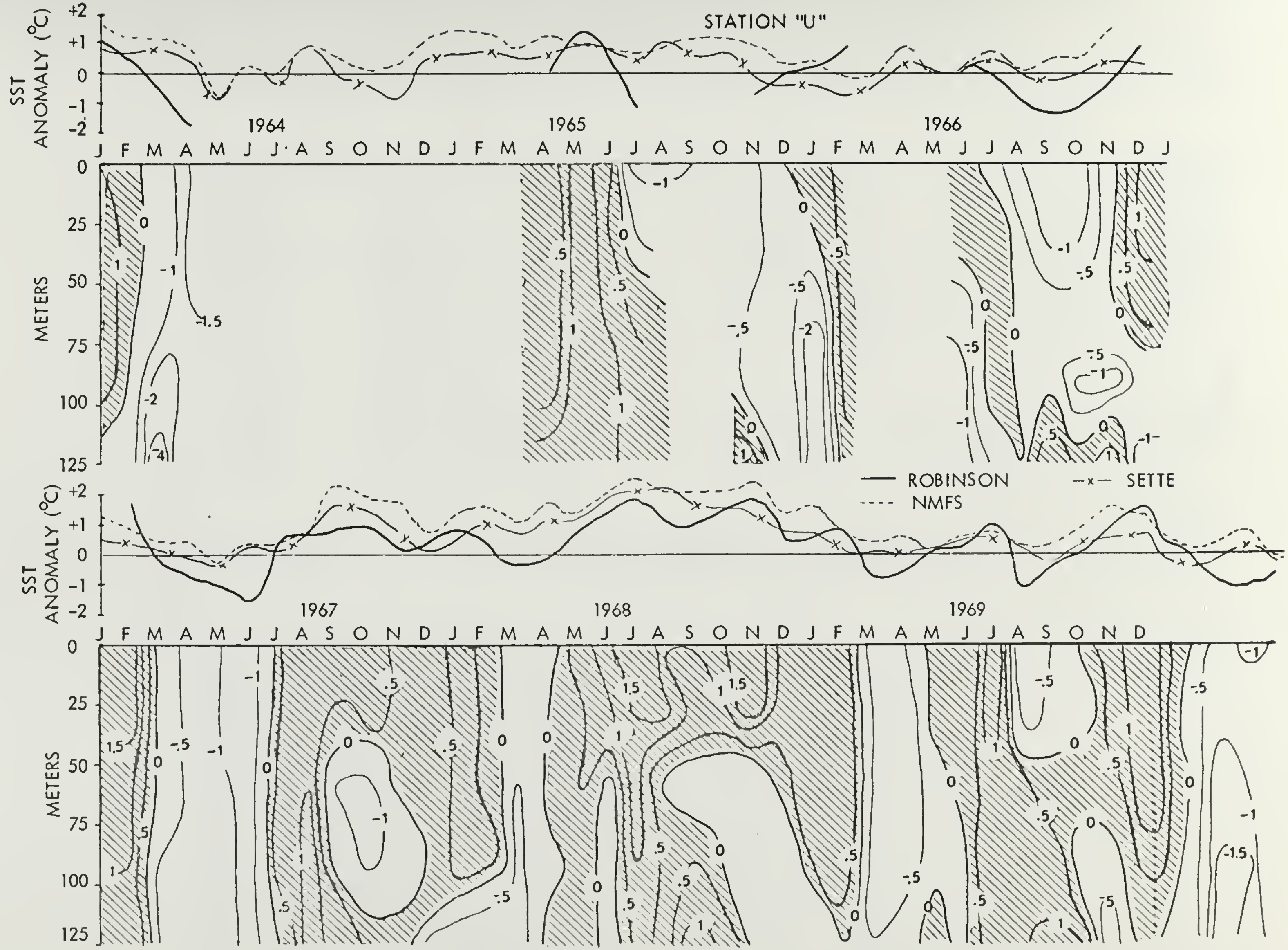


FIGURE 47. TIME SERIES PLOT OF VERTICAL TEMPERATURE ANOMALIES AT STATION U WITH COMPARISON OF ROBINSON, NMFS, AND SETTE SST ANOMALIES. THE SHADED AREAS INDICATE WARMER THAN NORMAL WATER.

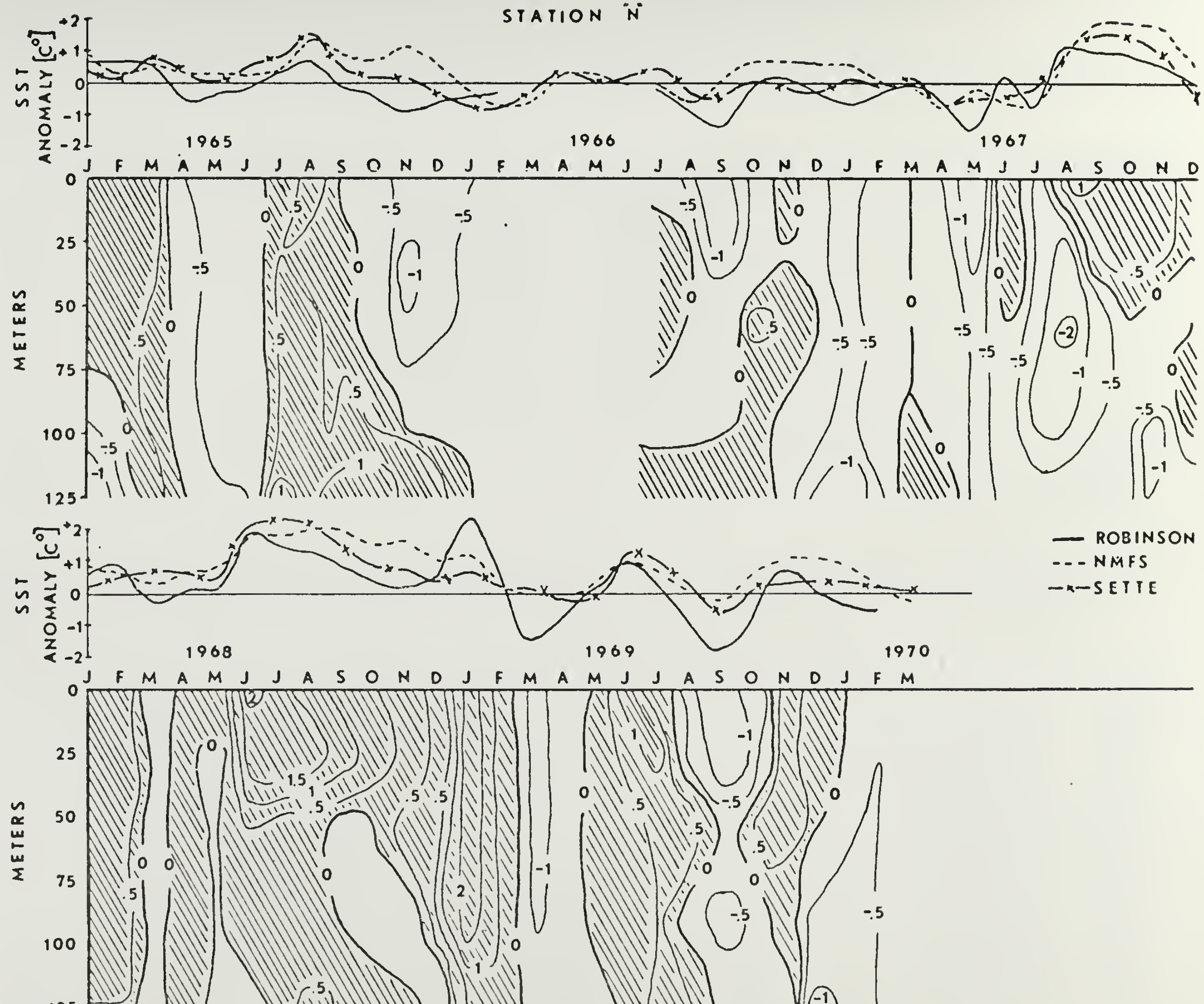


FIGURE 48. TIME SERIES PLOT OF VERTICAL TEMPERATURE ANOMALIES AT STATION N WITH COMPARISON OF ROBINSON, NMFS, AND SETTE SST ANOMALIES. THE SHADED AREAS INDICATE WARMER THAN NORMAL WATER.

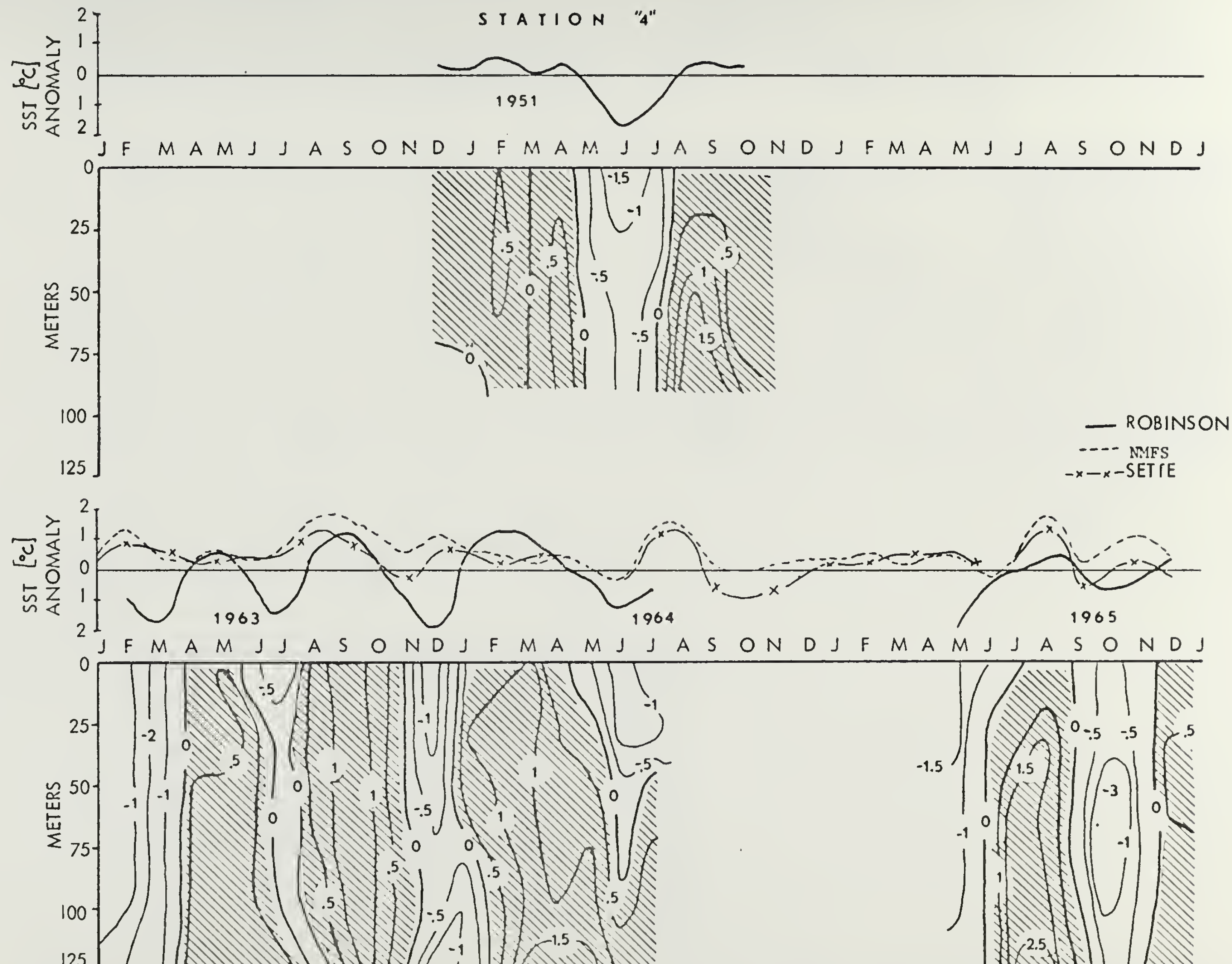


FIGURE 49. TIME SERIES PLOT OF VERTICAL TEMPERATURE ANOMALIES AT STATION 4 WITH COMPARISON OF ROBINSON, NMFS, AND SETTE SST ANOMALIES. THE SHADED AREAS INDICATE WARMER THAN NORMAL WATER.

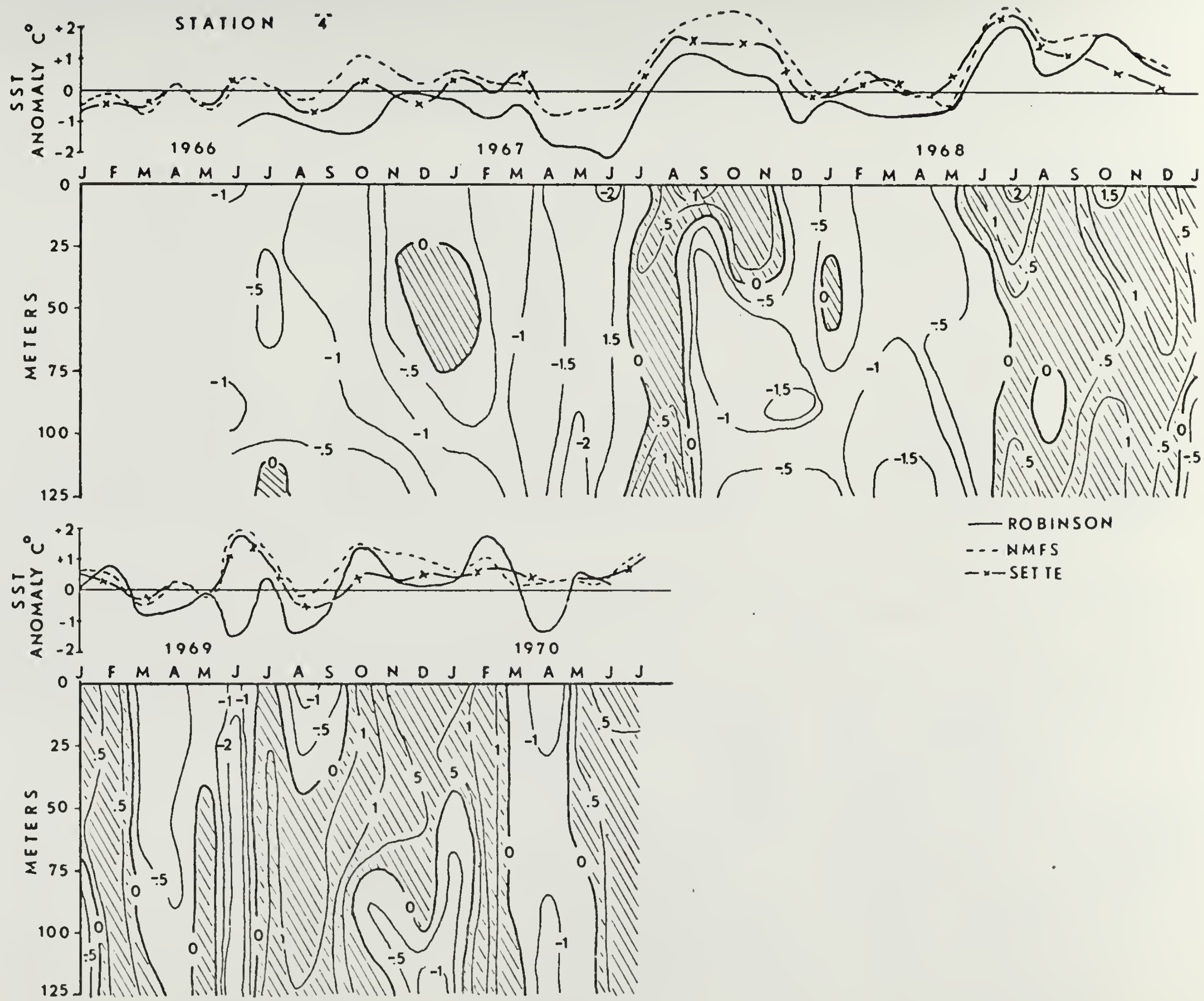


FIGURE 50. TIME SERIES PLOT OF VERTICAL TEMPERATURE ANOMALIES AT STATION 4 WITH COMPARISON OF ROBINSON, NMFS, AND SETTE SST ANOMALIES. THE SHADED AREAS INDICATE WARMER THAN NORMAL WATER.

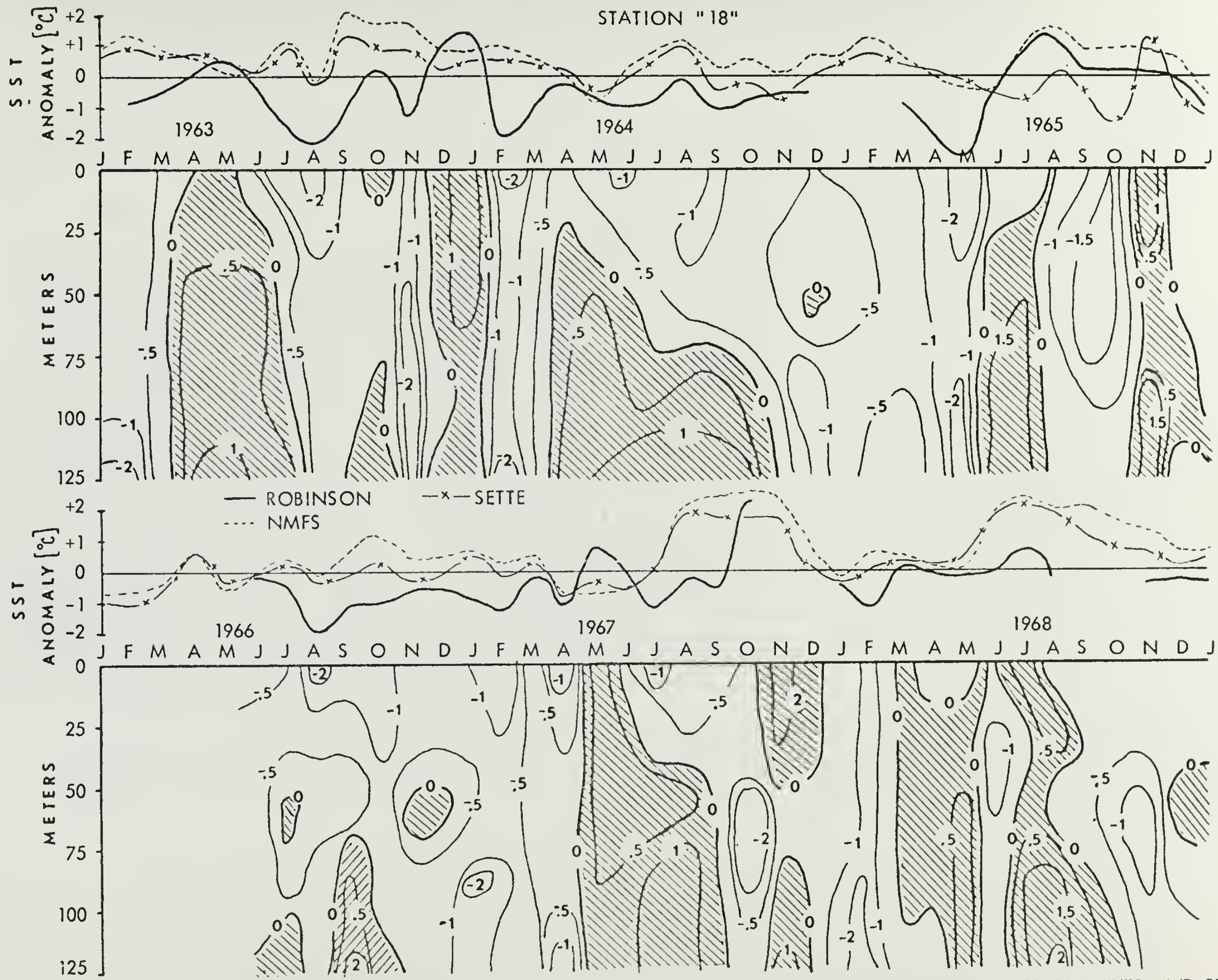


FIGURE 51. TIME SERIES PLOT OF VERTICAL TEMPERATURE ANOMALIES AT STATION 18 WITH COMPARISON OF ROBINSON, NMFS, AND SETTE SST ANOMALIES. THE SHADED AREAS INDICATE WARMER THAN NORMAL WATER.

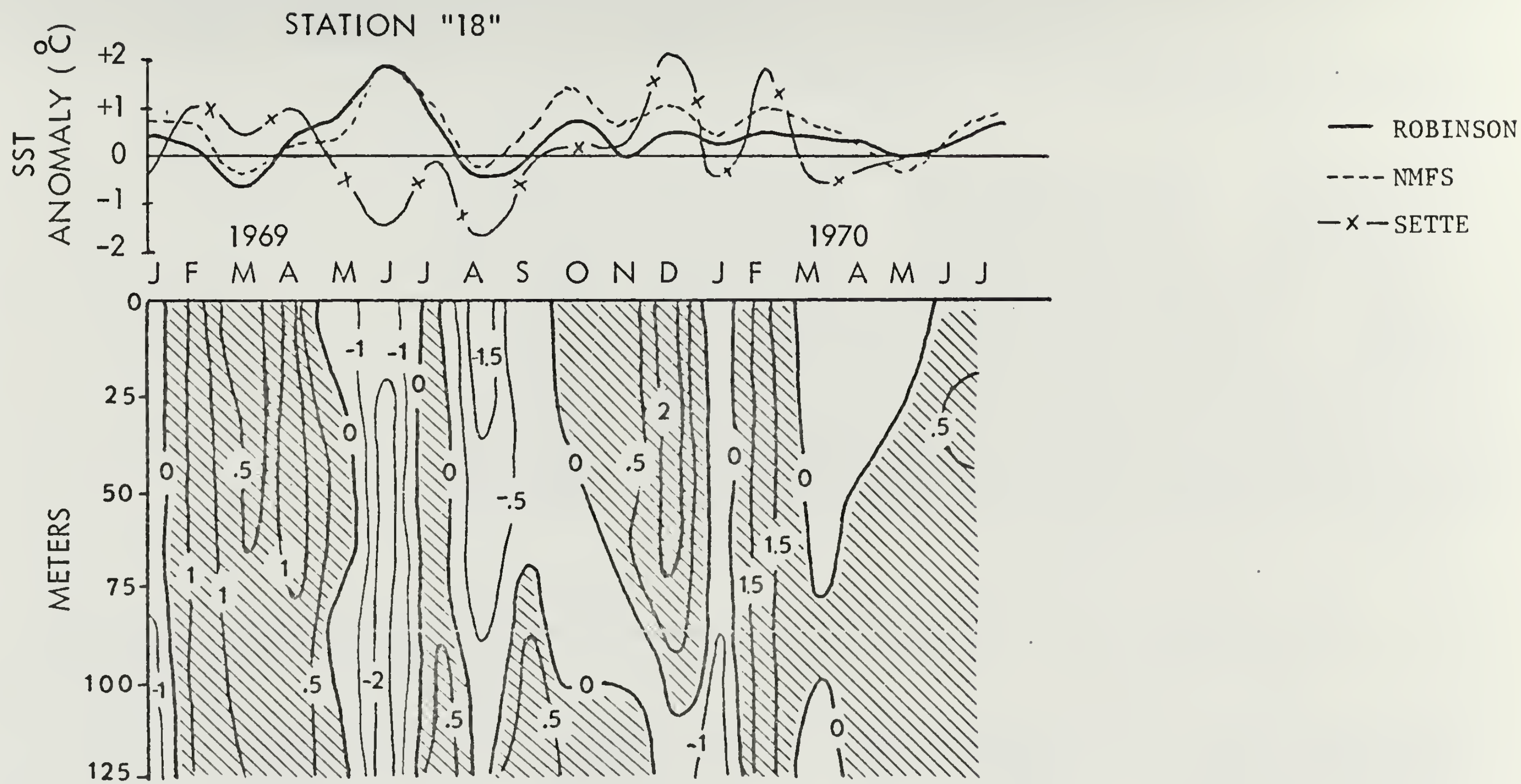


FIGURE 52. TIME SERIES PLOT OF VERTICAL TEMPERATURE ANOMALIES AT STATION 18 WITH COMPARISON OF ROBINSON, NMFS, AND SETTE SST ANOMALIES. THE SHADED AREAS INDICATE WARMER THAN NORMAL WATER.

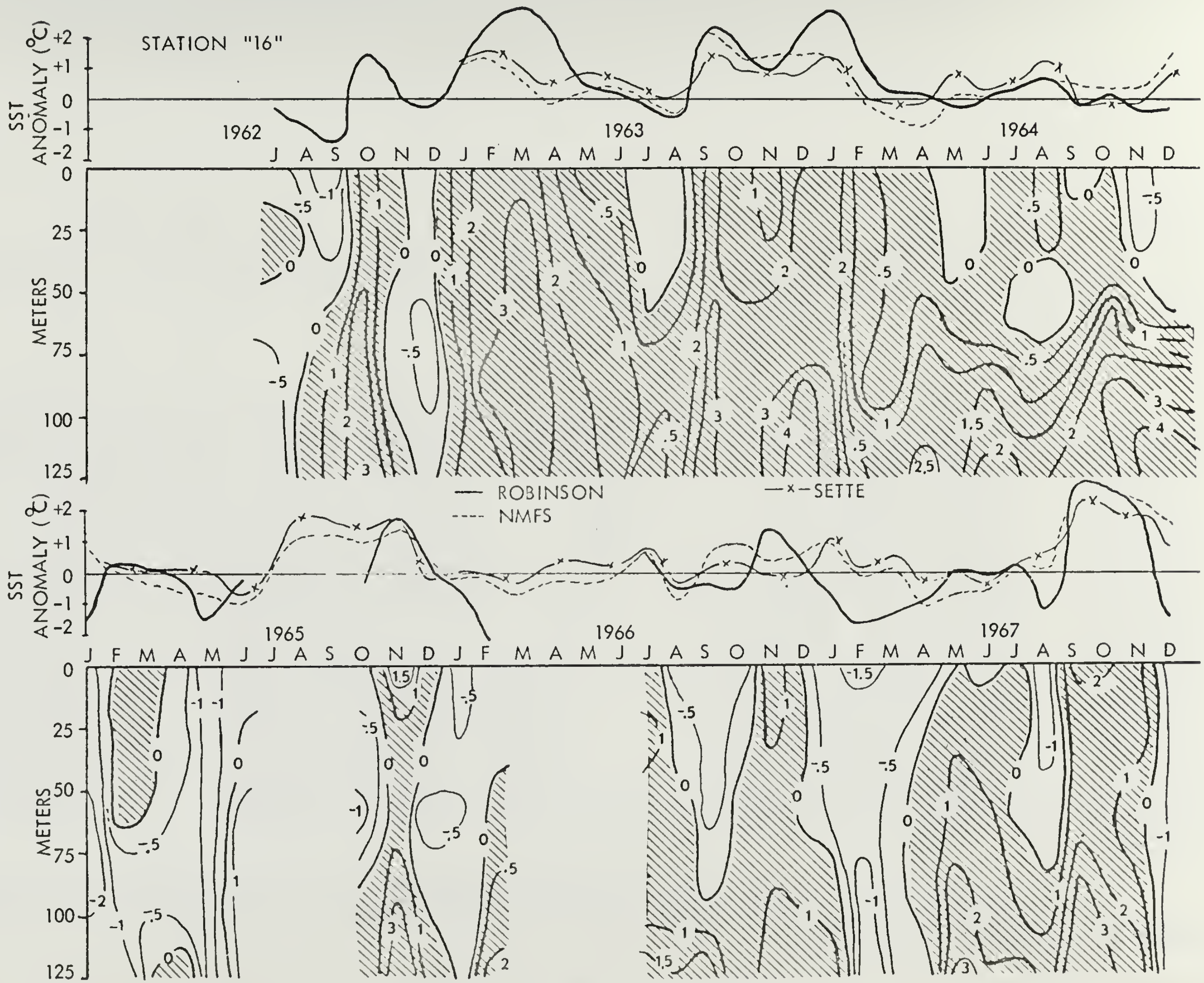


FIGURE 53. TIME SERIES PLOT OF VERTICAL TEMPERATURE ANOMALIES AT STATION 16 WITH COMPARISON OF ROBINSON, NMFS AND SETTE SST ANOMALIES. THE SHADED AREAS INDICATE WARMER THAN NORMAL WATER.

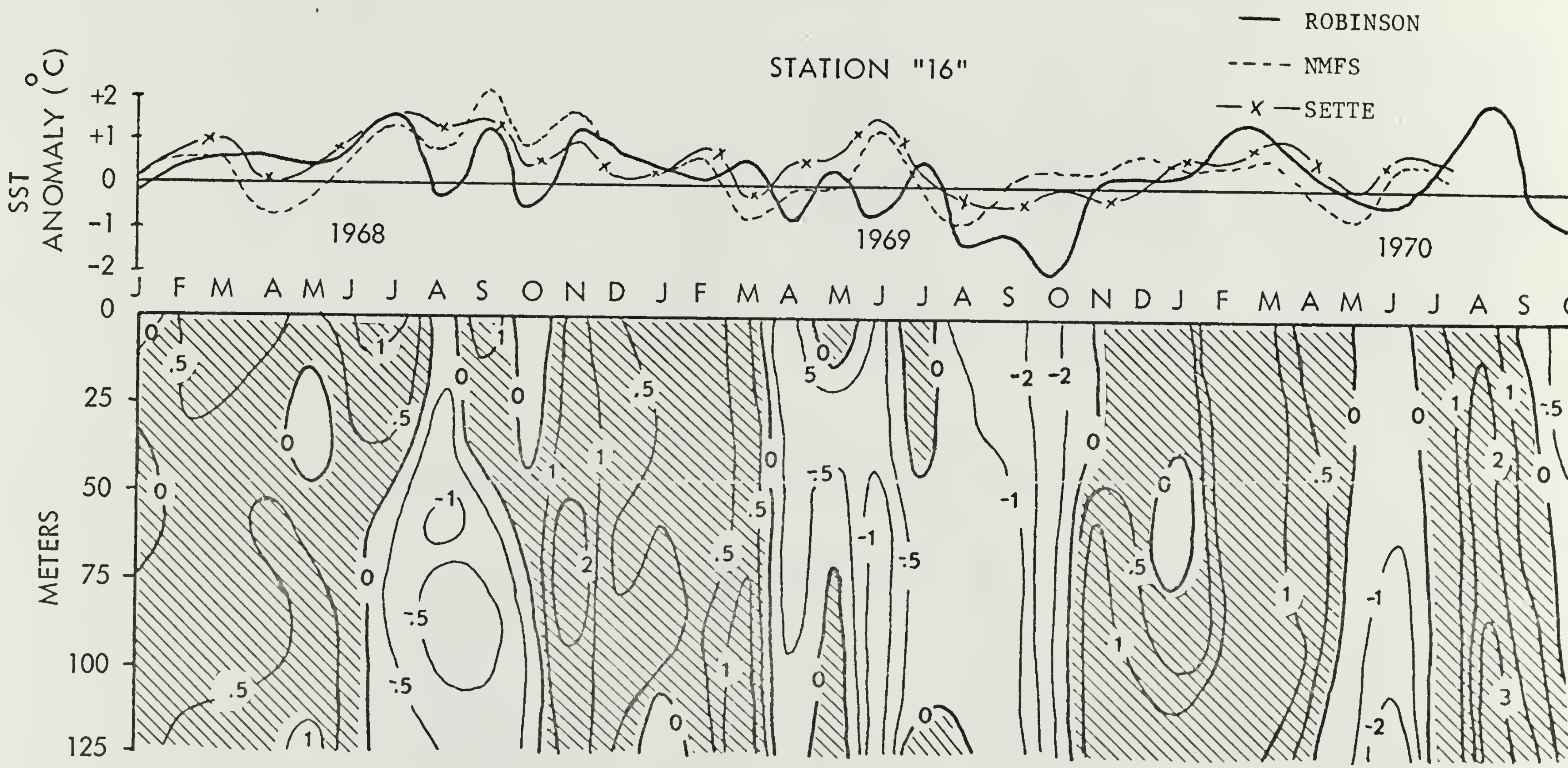


FIGURE 54. TIME SERIES PLOT OF VERTICAL TEMPERATURE ANOMALIES AT STATION 16 WITH COMPARISON OF ROBINSON, NMFS, AND SETTE SST ANOMALIES. THE SHADED AREAS INDICATE WARMER THAN NORMAL WATER.

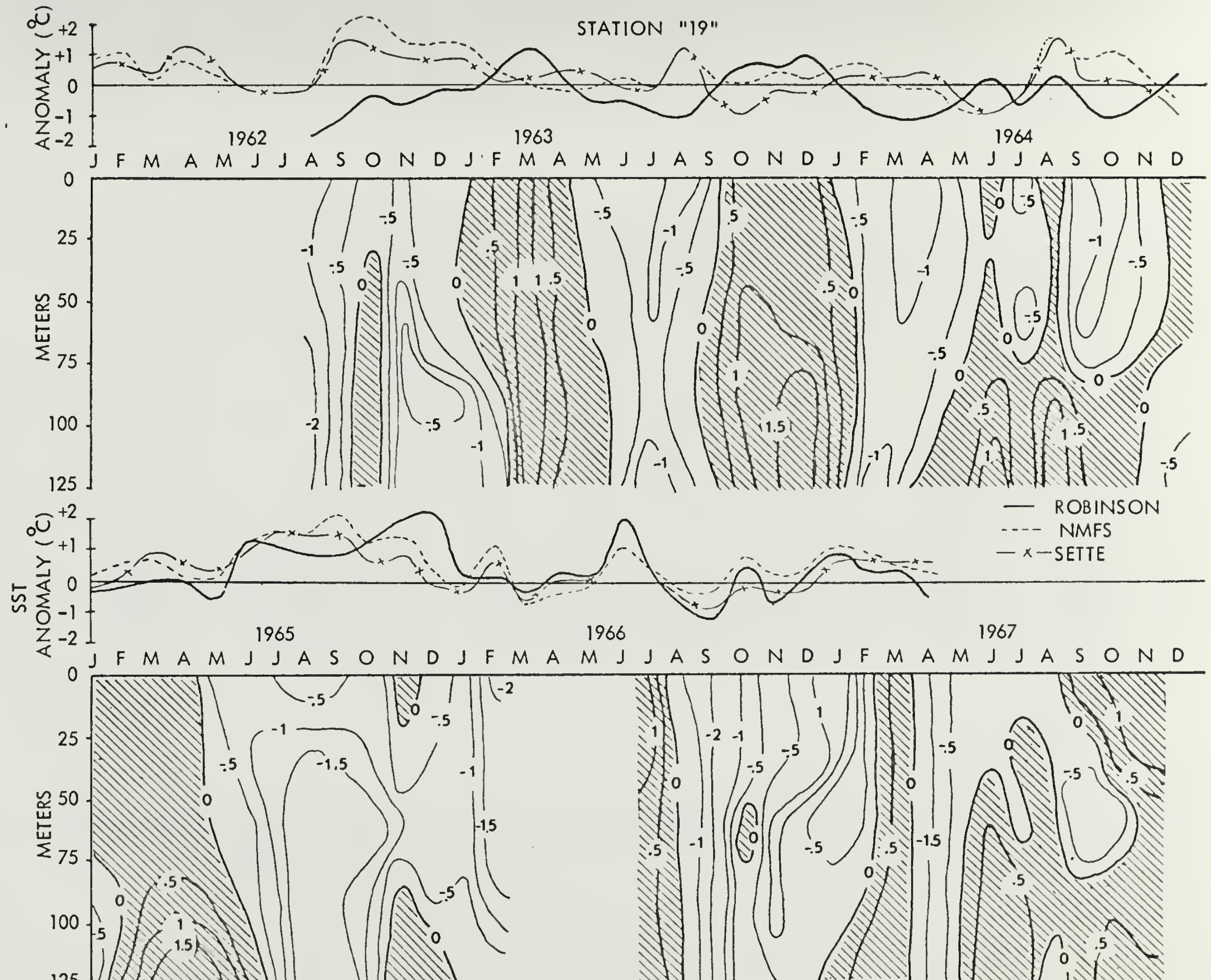


FIGURE 55. TIME SERIES PLOT OF VERTICAL TEMPERATURE ANOMALIES AT STATION 19 WITH COMPARISON OF ROBINSON, NMFS, AND SETTE SST ANOMALIES. THE SHADED AREAS INDICATE WARMER THAN NORMAL WATER.

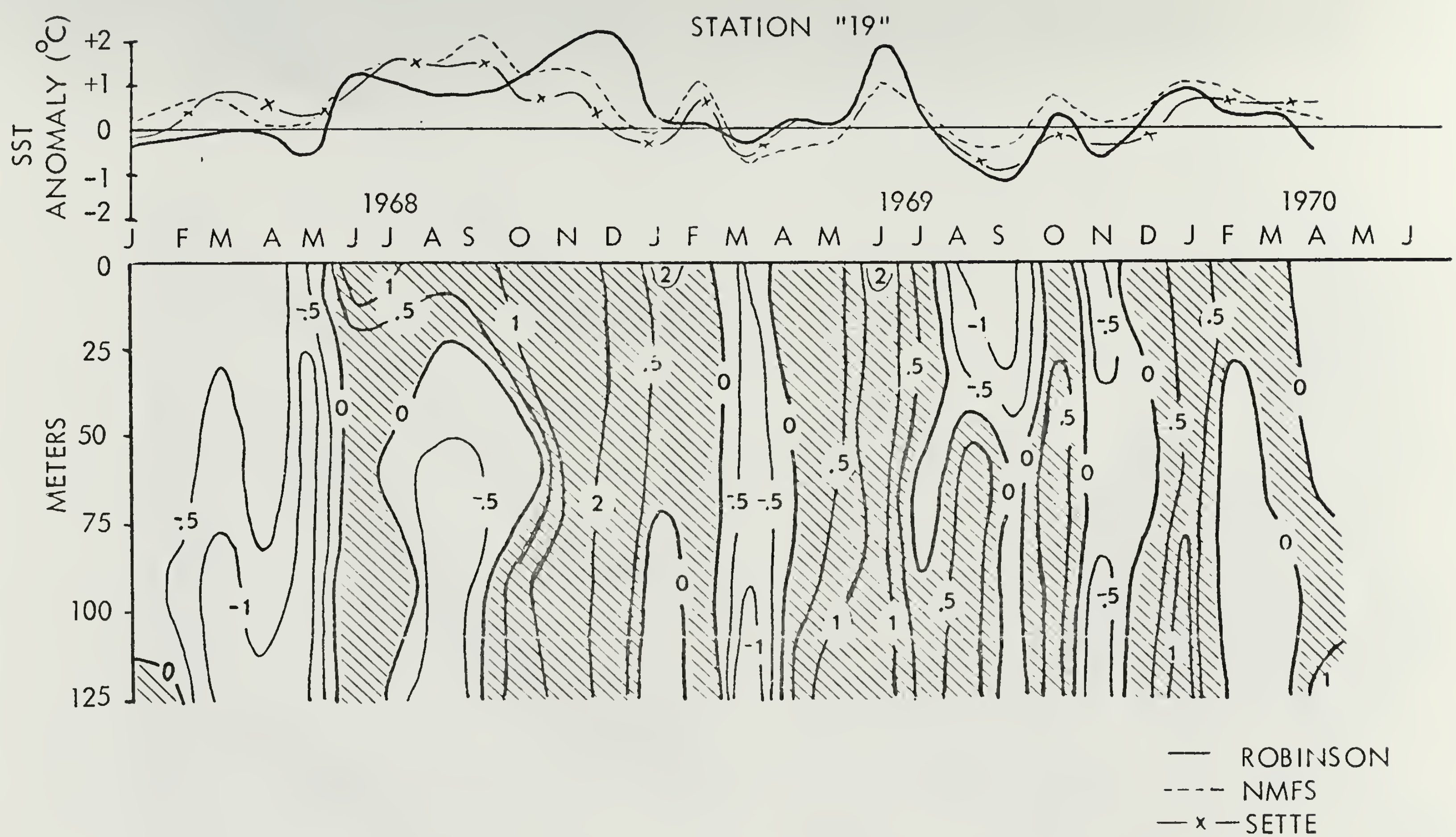


FIGURE 56. TIME SERIES PLOT OF VERTICAL TEMPERATURE ANOMALIES AT STATION 19 WITH COMPARISON OF ROBINSON, NMFS, AND SETTE SST ANOMALIES. THE SHADED AREAS INDICATE WARMER THAN NORMAL WATER.

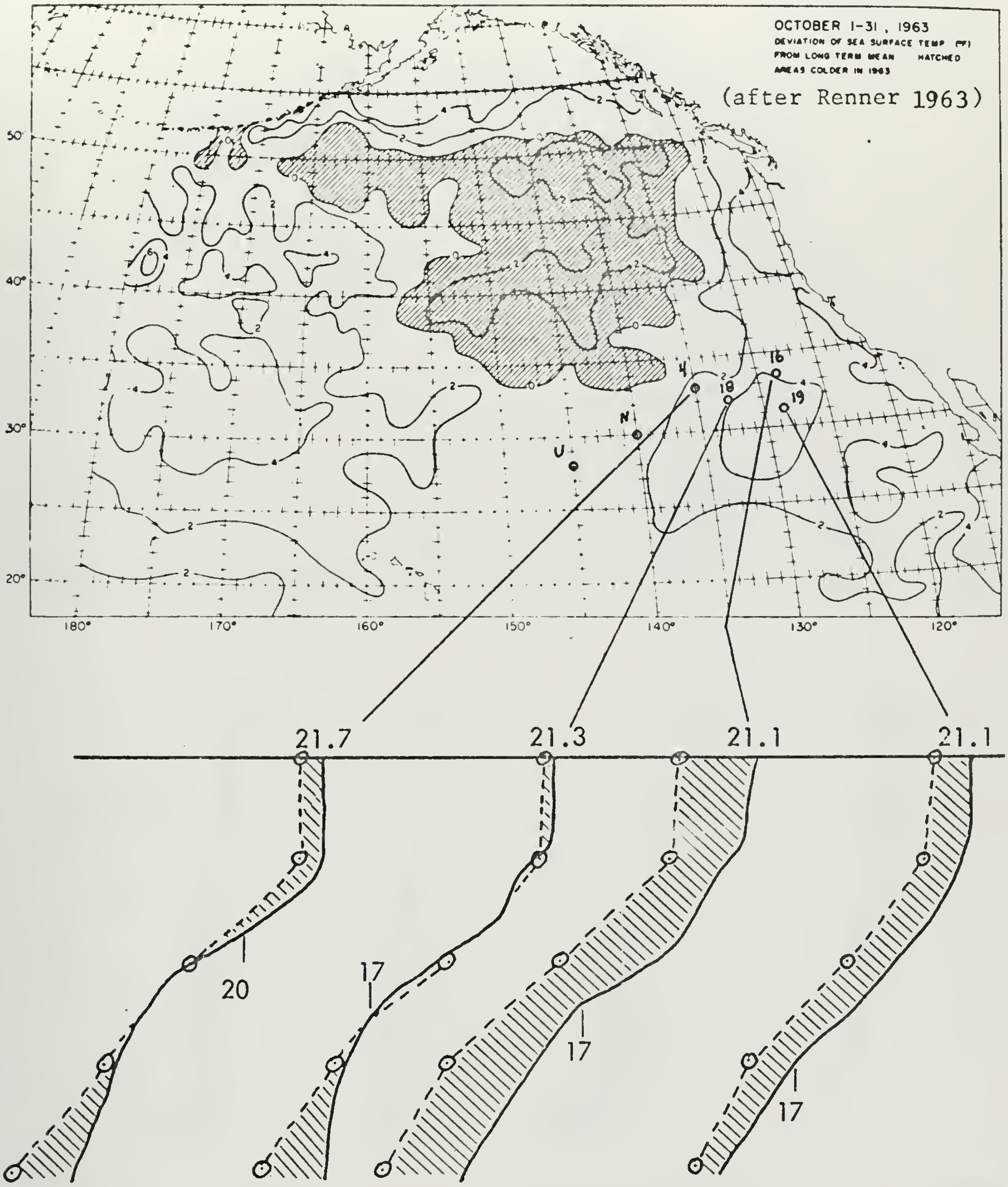


FIGURE 57. COMPARISON OF SURFACE ANOMALY CHART WITH THE ASSOCIATED SUBSURFACE THERMAL STRUCTURE FOR OCTOBER 1963. SHADED AREAS ON BT's INDICATES WARMER THAN NORMAL WATER.

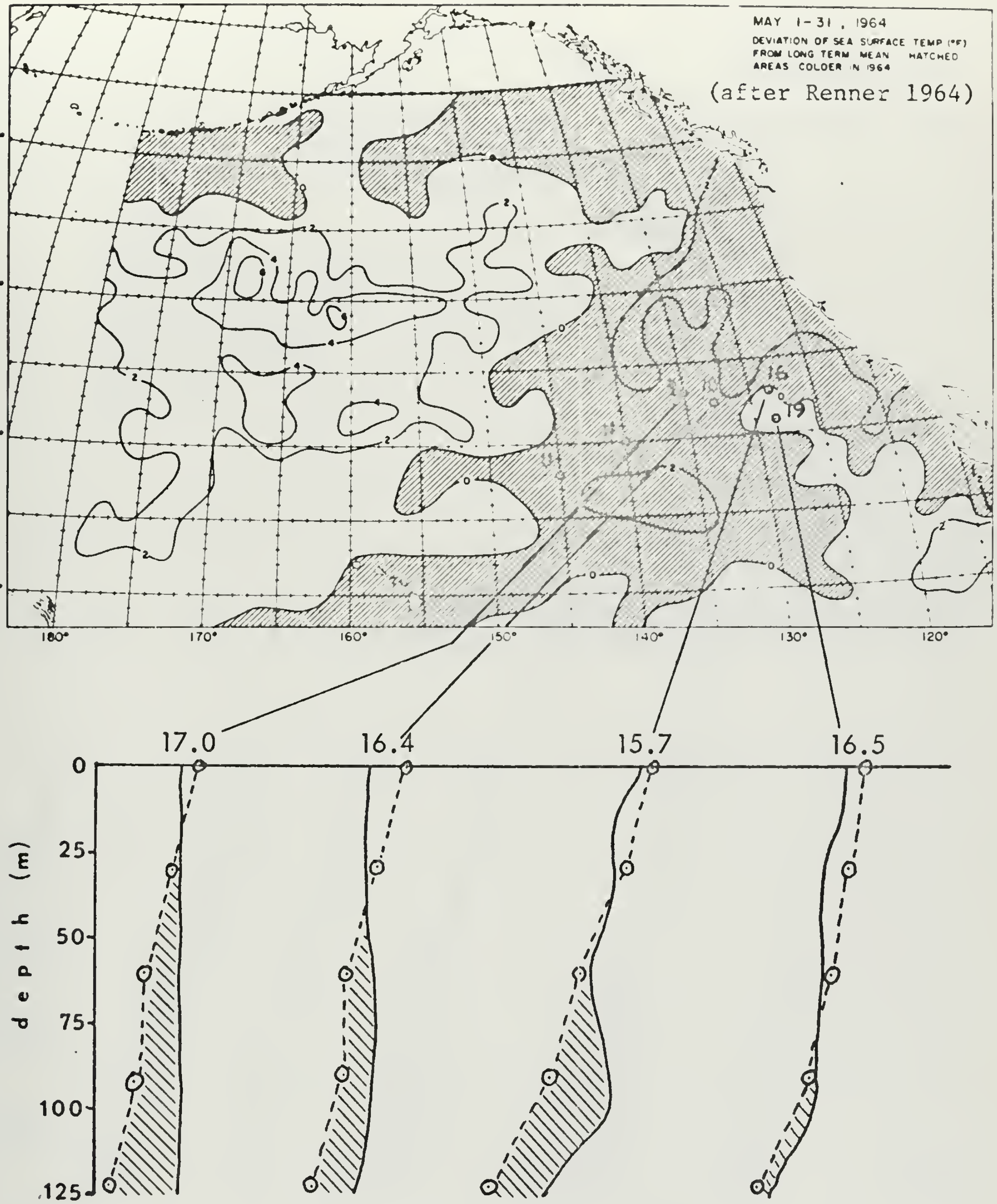


FIGURE 58. COMPARISON OF SURFACE ANOMALY CHART WITH THE ASSOCIATED SUBSURFACE THERMAL STRUCTURE FOR MAY 1964. SHADED AREAS ON BT's INDICATES WARMER THAN NORMAL WATER.

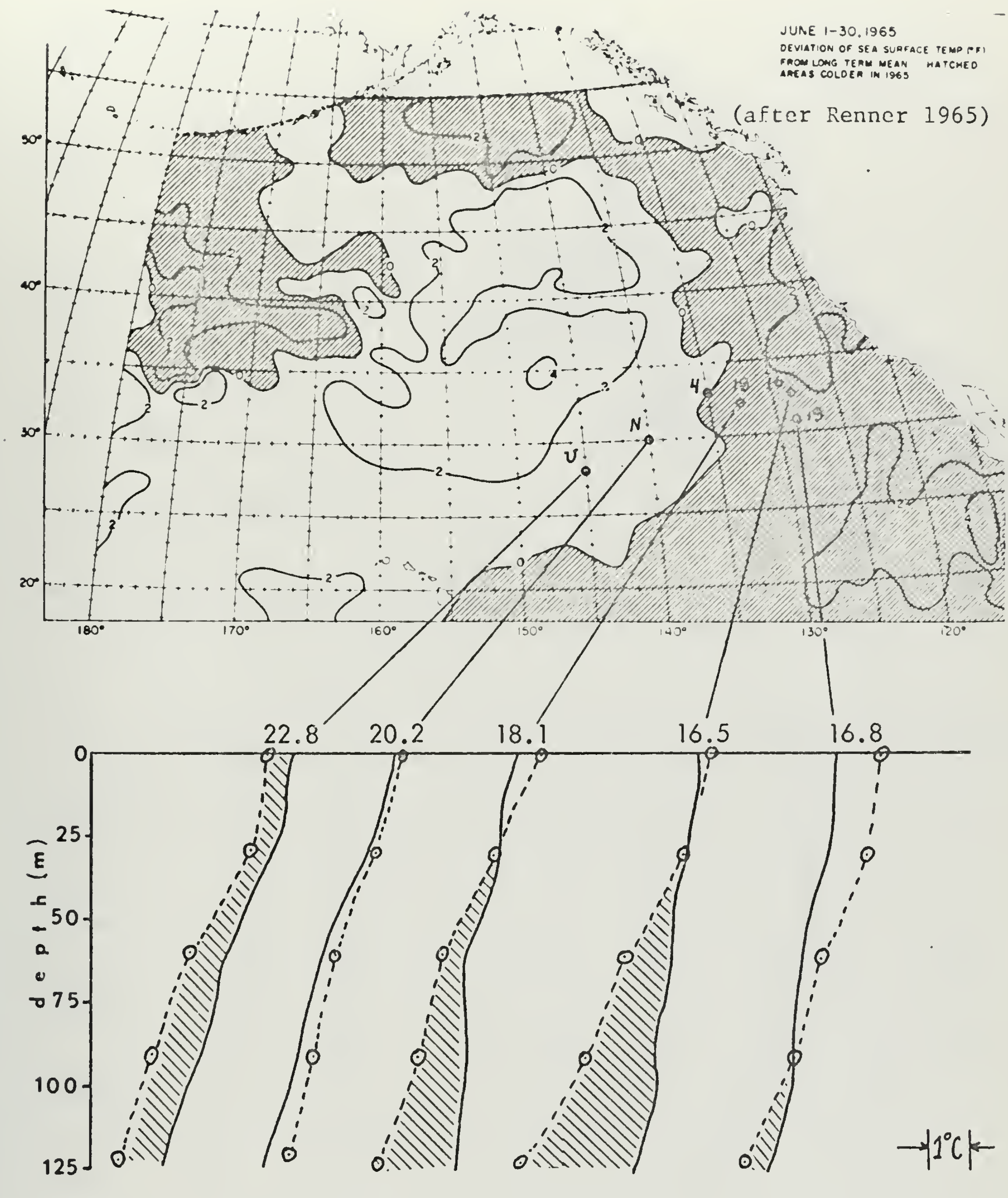


FIGURE 59. COMPARISON OF SURFACE ANOMALY CHART WITH THE ASSOCIATED SUBSURFACE THERMAL STRUCTURE FOR JUNE 1965. SHADED AREAS ON BT's INDICATES WARMER THAN NORMAL WATER.

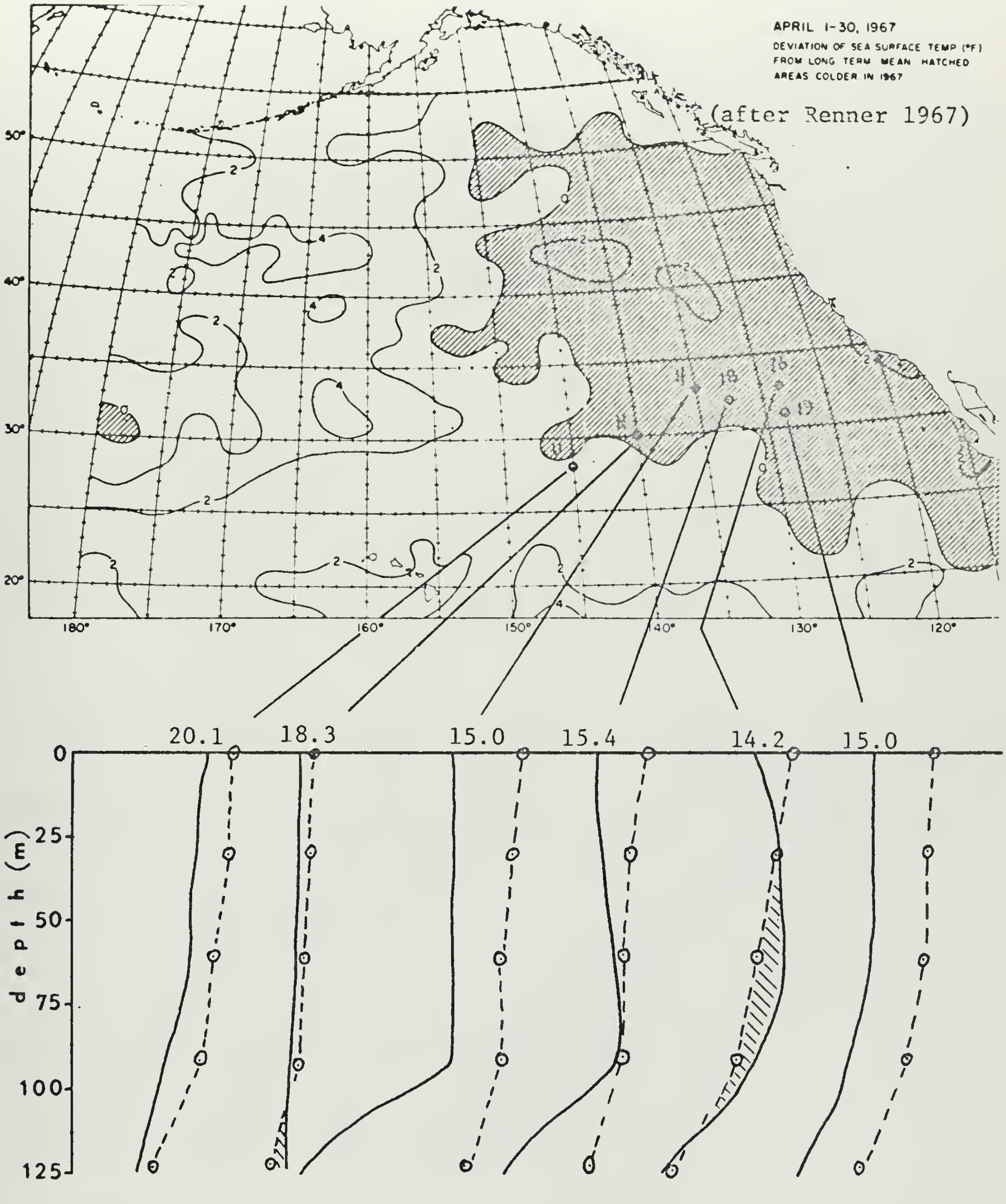


FIGURE 60. COMPARISON OF SURFACE ANOMALY CHART WITH THE ASSOCIATED SUBSURFACE THERMAL STRUCTURE FOR APRIL 1967. SHADED AREAS ON BT's INDICATES WARMER THAN NORMAL WATER.

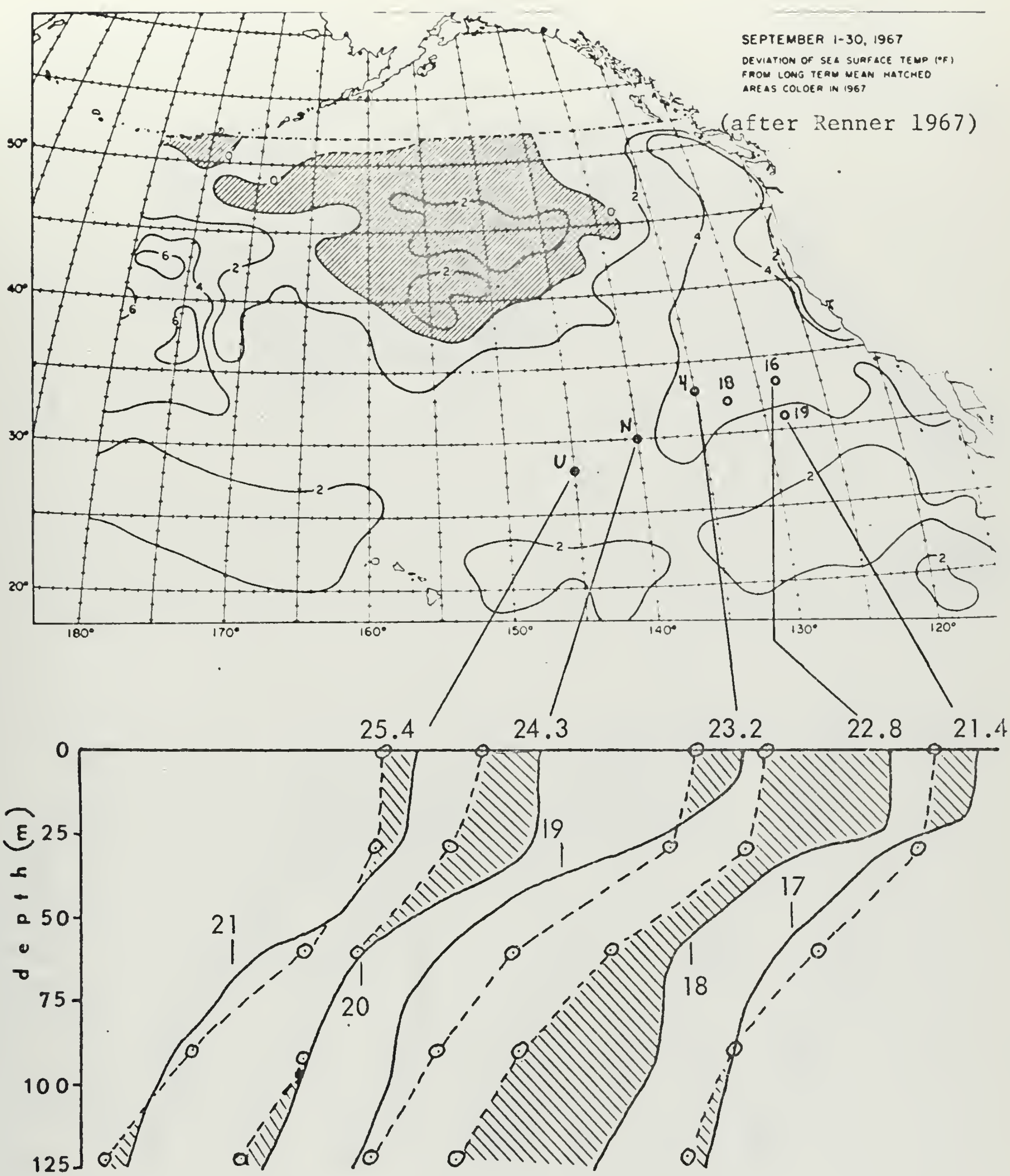


FIGURE 61. COMPARISON OF SURFACE ANOMALY CHART WITH THE ASSOCIATED SUBSURFACE THERMAL STRUCTURE FOR SEPTEMBER 1967. SHADED AREAS ON BT's INDICATES WARMER THAN NORMAL WATER.

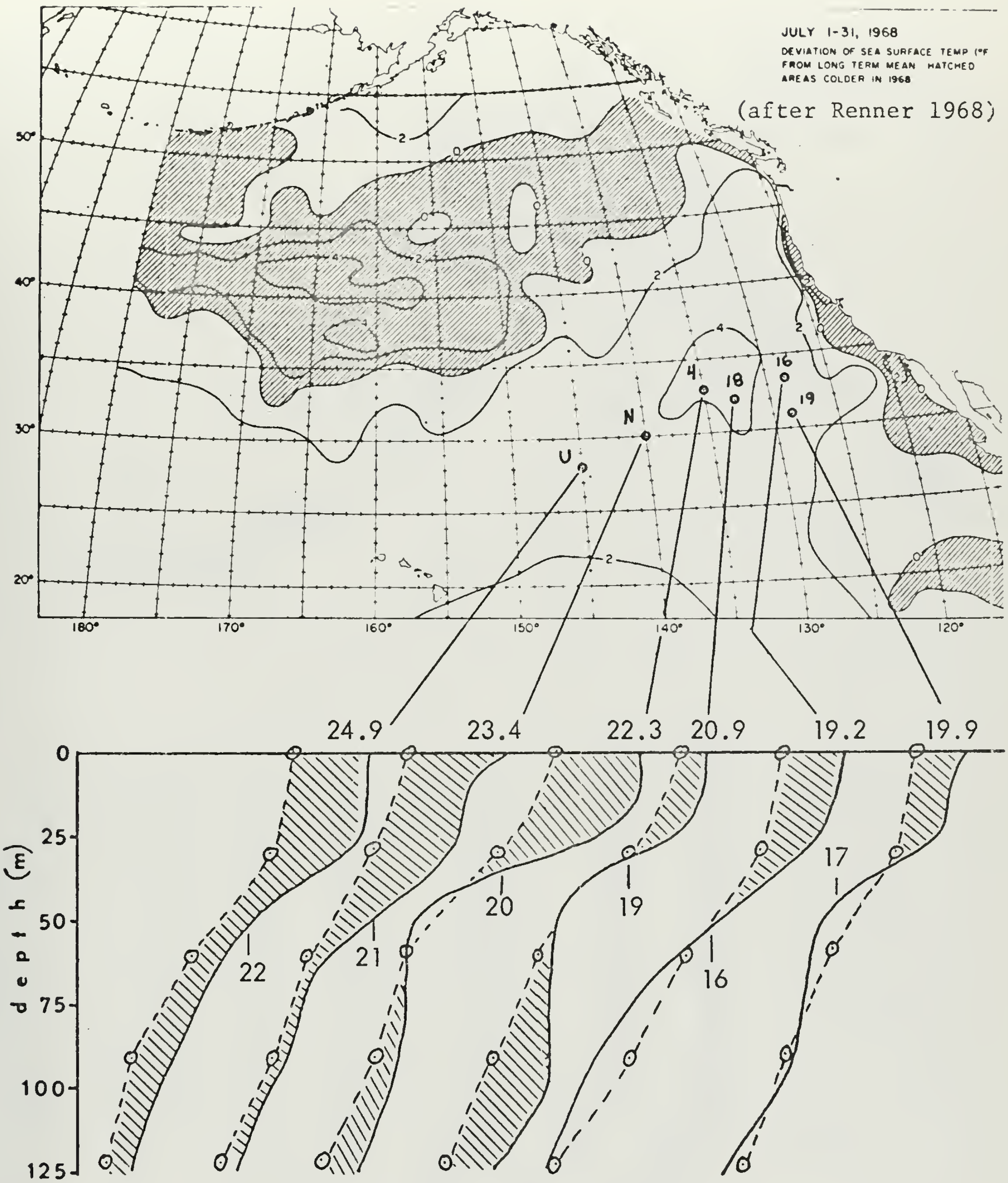


FIGURE 62. COMPARISON OF SURFACE ANOMALY CHART WITH THE ASSOCIATED SUBSURFACE THERMAL STRUCTURE FOR JULY 1968. SHADED AREAS ON BT's INDICATES WARMER THAN NORMAL WATER.

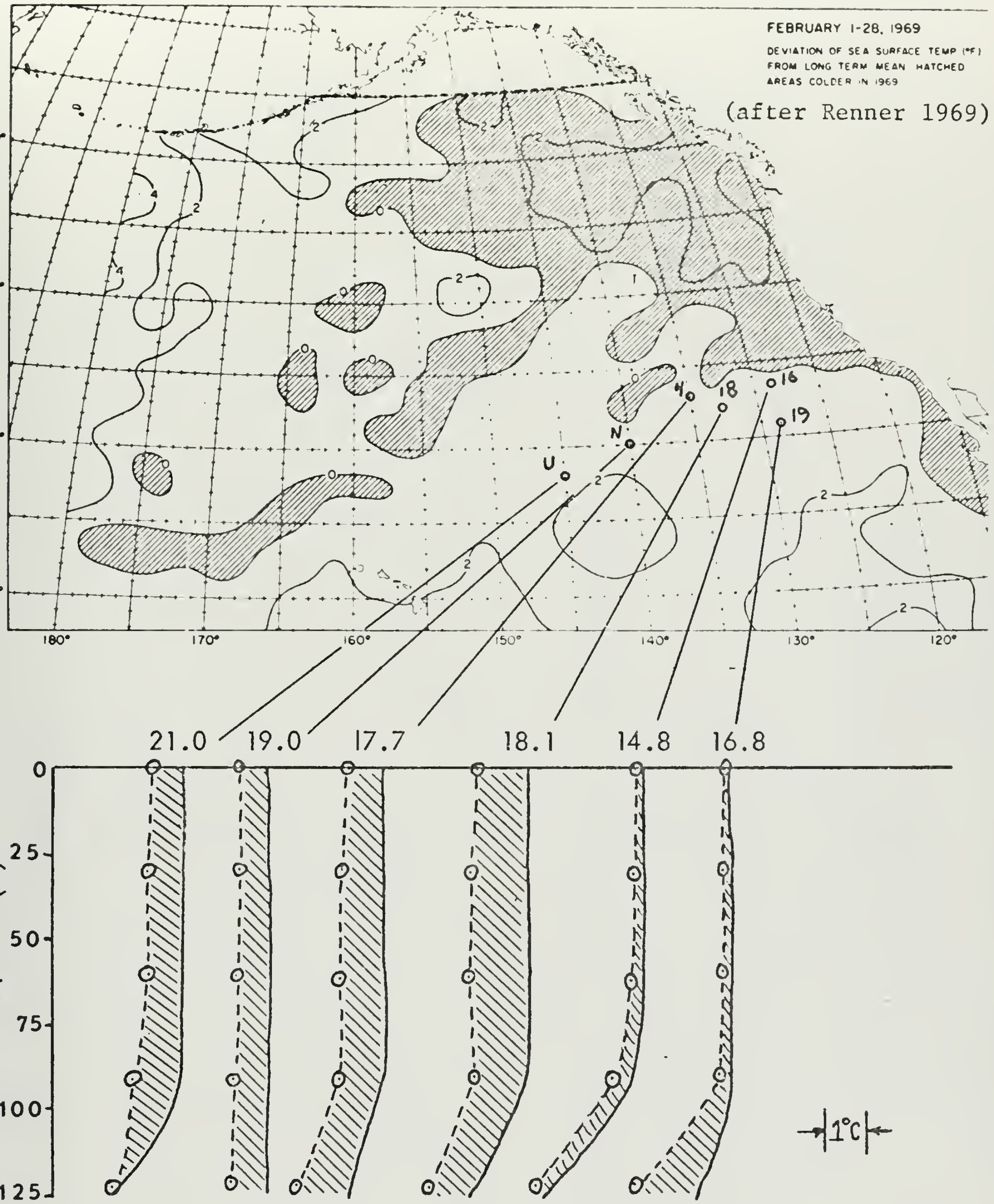


FIGURE 63. COMPARISON OF SURFACE ANOMALY CHART WITH THE ASSOCIATED SUBSURFACE THERMAL STRUCTURE FOR FEBRUARY 1969. SHADED AREAS ON BT's INDICATES WARMER THAN NORMAL WATER.

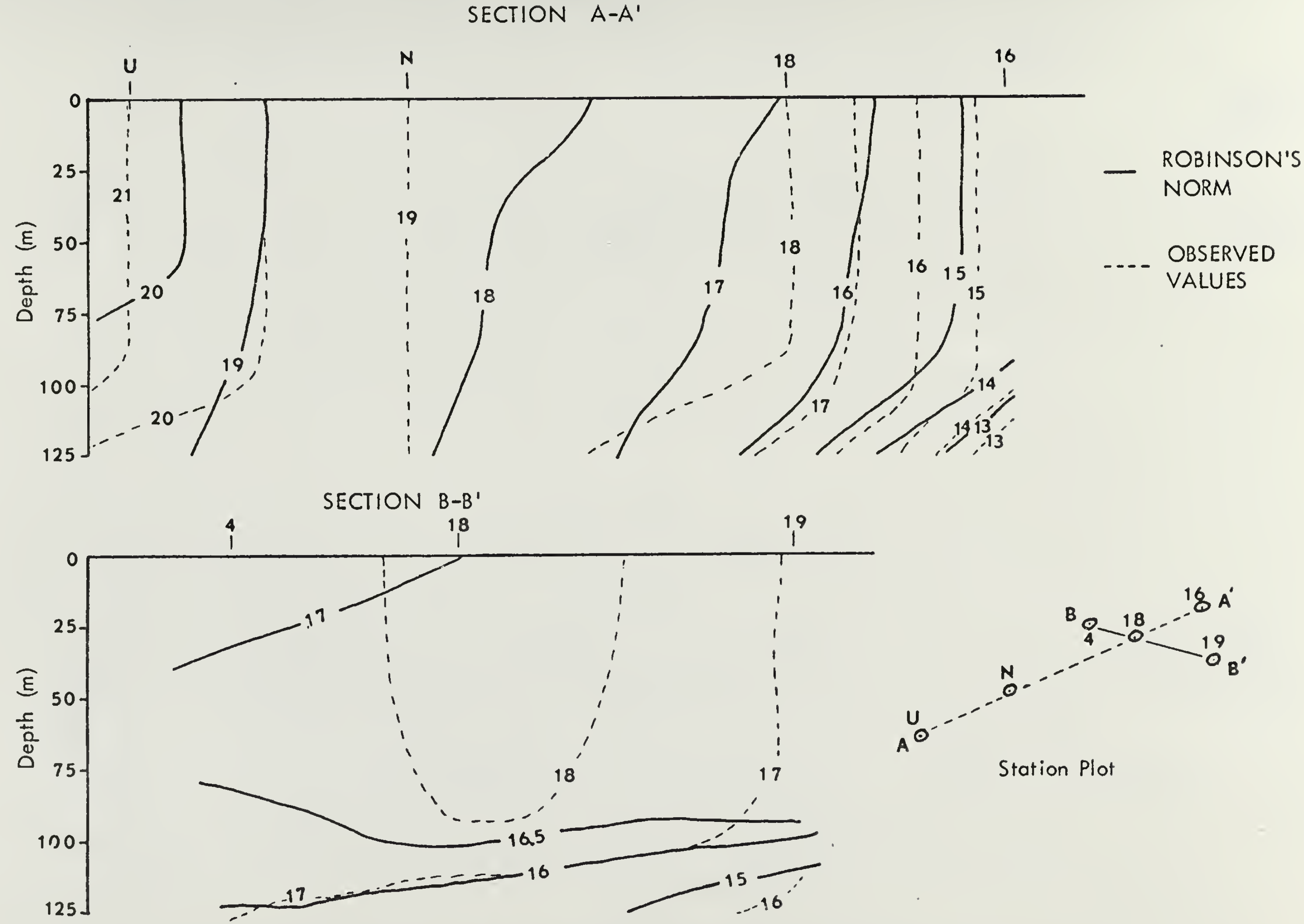


FIGURE 64. VERTICAL SECTIONS OF TEMPERATURES (^{o}C) FOR FEBRUARY 1969 COMPARING NORM TO OBSERVED VALUES ALONG LINES AS INDICATED IN STATION PLOT.

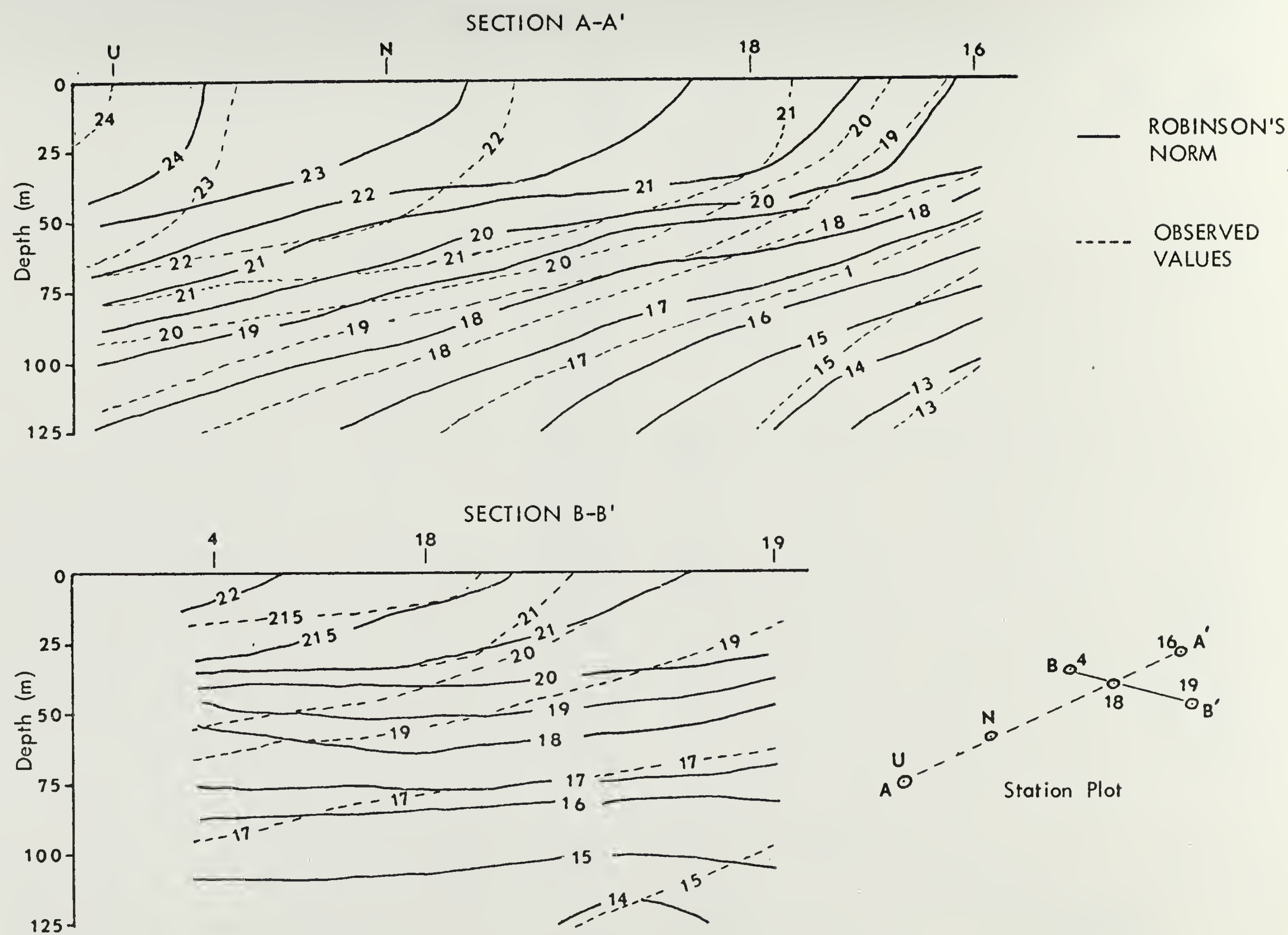


FIGURE 65. VERTICAL SECTIONS OF TEMPERATURES (^{o}C) FOR SEPTEMBER 1969 COMPARING NORM TO OBSERVED VALUES ALONG LINES AS INDICATED IN STATION PLOT.

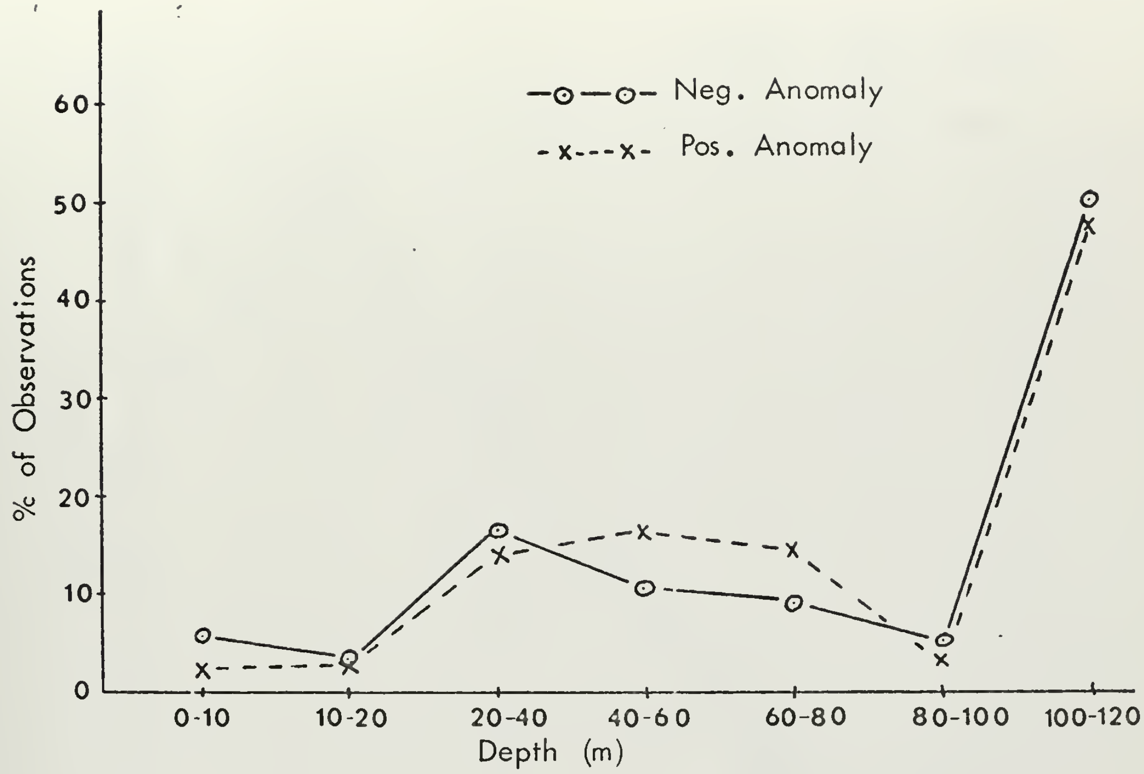


FIGURE 66. PLOT OF DEPTHS TO WHICH THE SURFACE ANOMALY EXISTED VERSUS THE PERCENTAGE OF THE TOTAL OBSERVATIONS FOR ALL STATIONS.

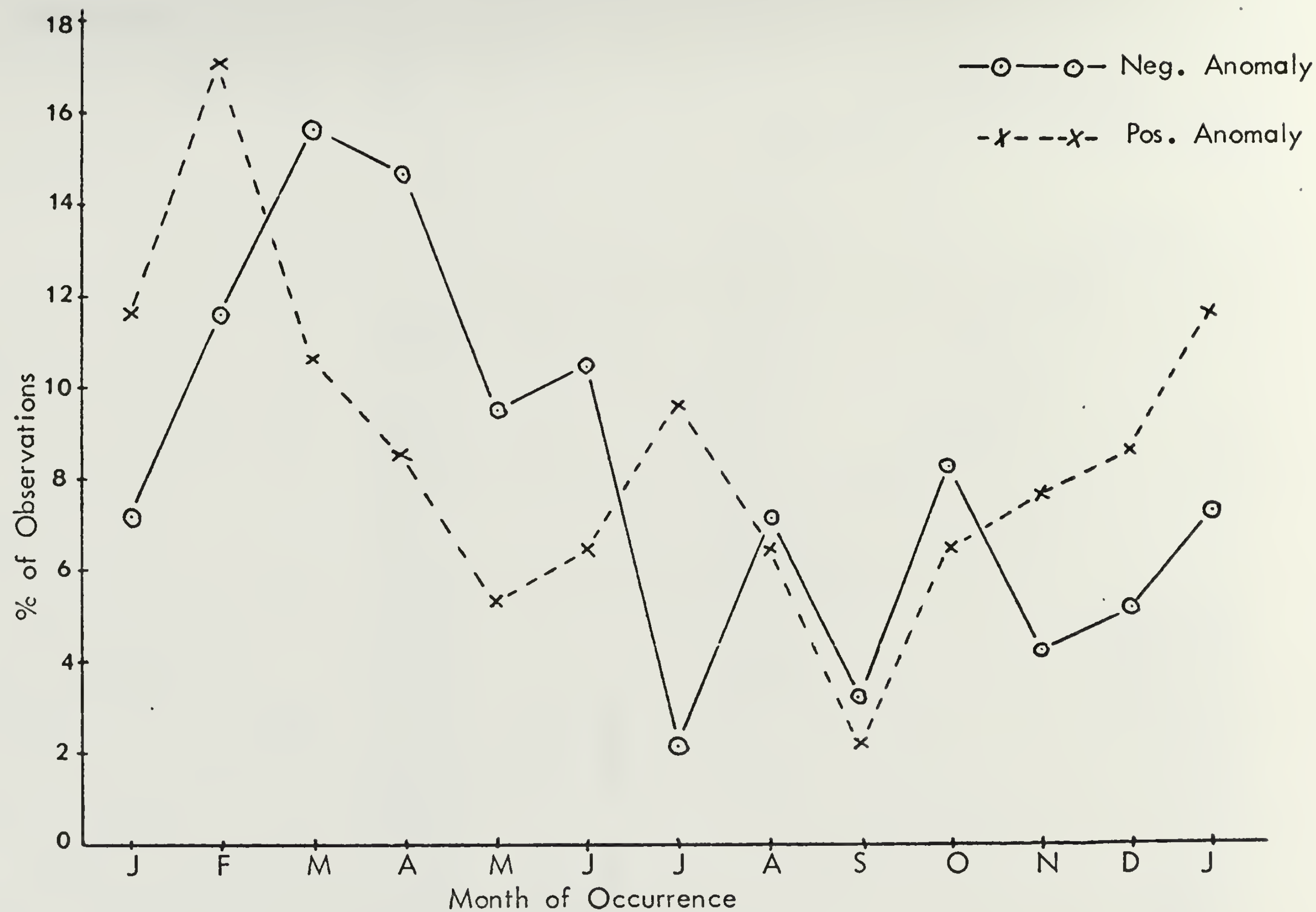


FIGURE 68. PLOT OF MONTH OF OCCURRENCE FOR SURFACE ANOMALIES THAT EXISTED TO 100M VERSUS THE PERCENTAGE OF THE TOTAL OBSERVATIONS FOR ALL STATIONS.

FIGURE 69. PLOT OF THE MAGNITUDE OF THE SURFACE ANOMALY THAT EXISTED 40M VERSUS THE PERCENTAGE OF THE TOTAL OBSERVATIONS FOR ALL STATIONS.

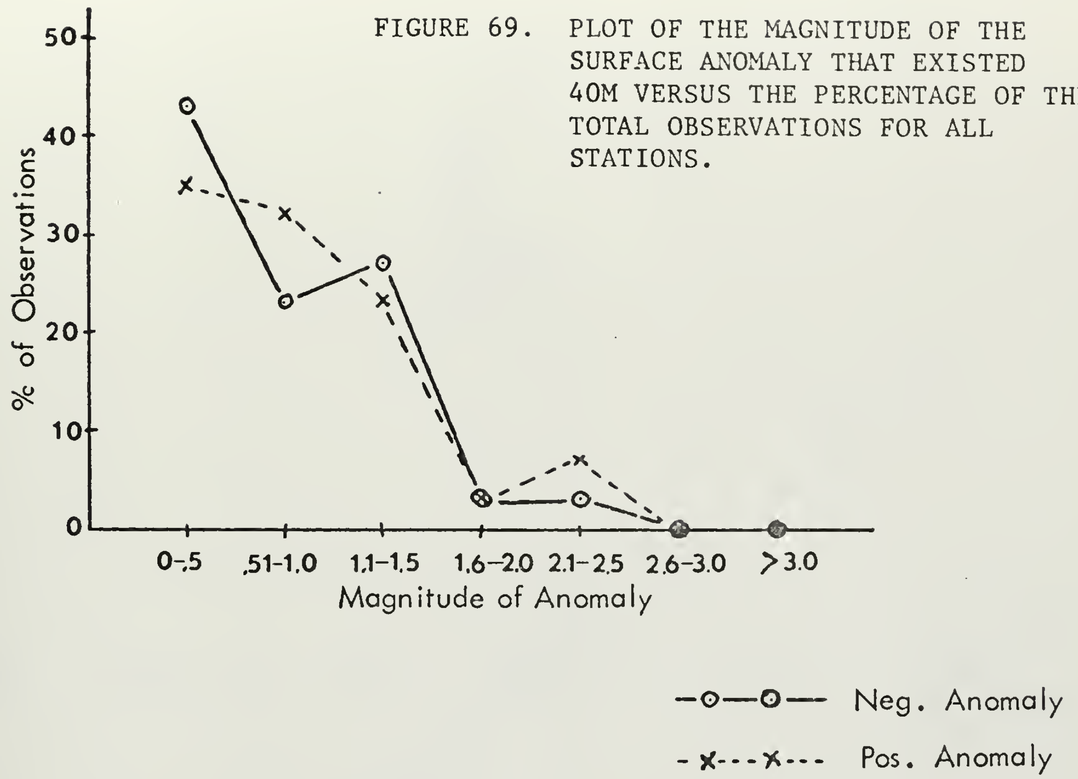
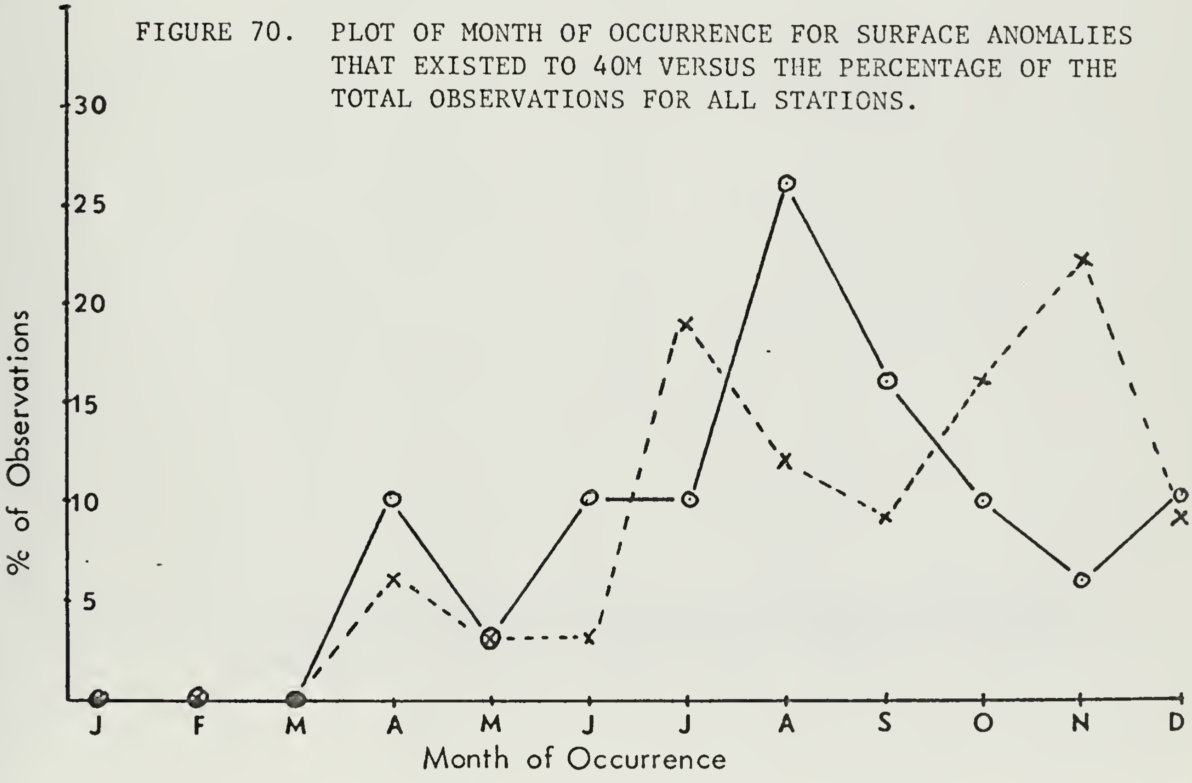


FIGURE 70. PLOT OF MONTH OF OCCURRENCE FOR SURFACE ANOMALIES THAT EXISTED TO 40M VERSUS THE PERCENTAGE OF THE TOTAL OBSERVATIONS FOR ALL STATIONS.



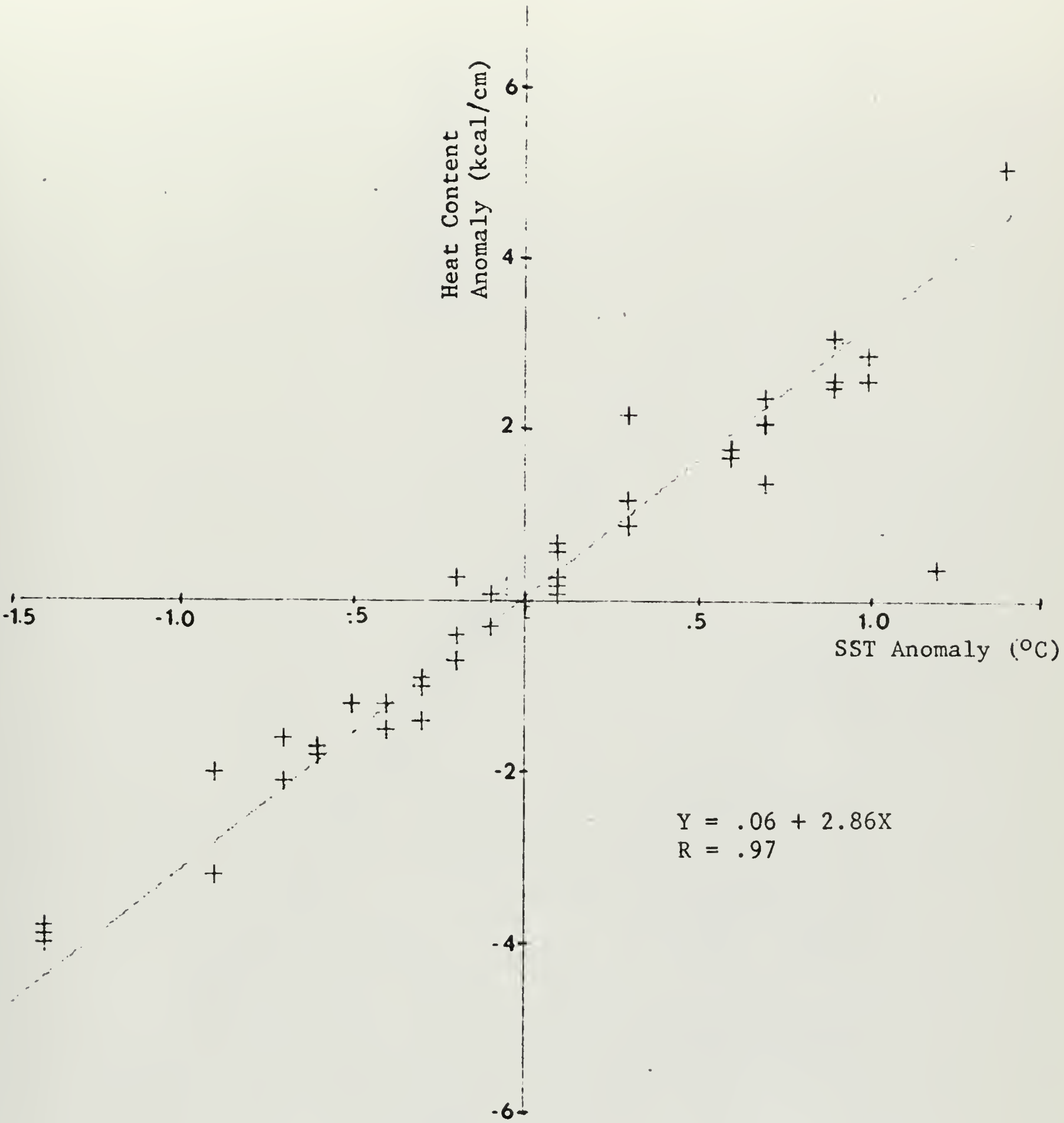


FIGURE 71. CORRELATION PLOT OF SST ANOMALY VERSUS HEAT CONTENT ANOMALY AT STATION N FROM 0-30M. (R=CORR. COEF.)

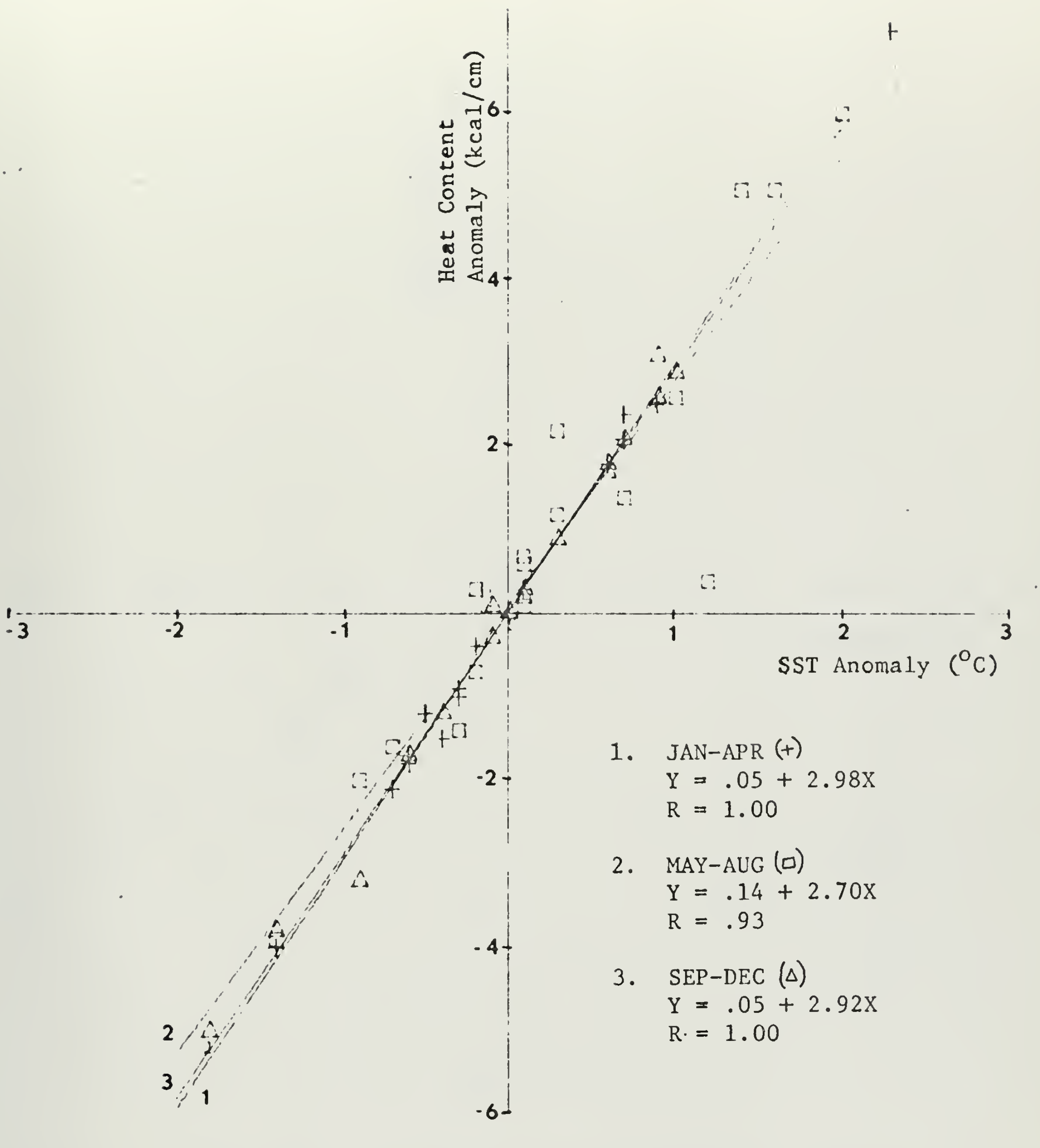


FIGURE 72. CORRELATION PLOT BY SEASON OF SST ANOMALY VERSUS HEAT CONTENT ANOMALY AT STATION N FROM 0-30M. (R = CORR. COEF.)

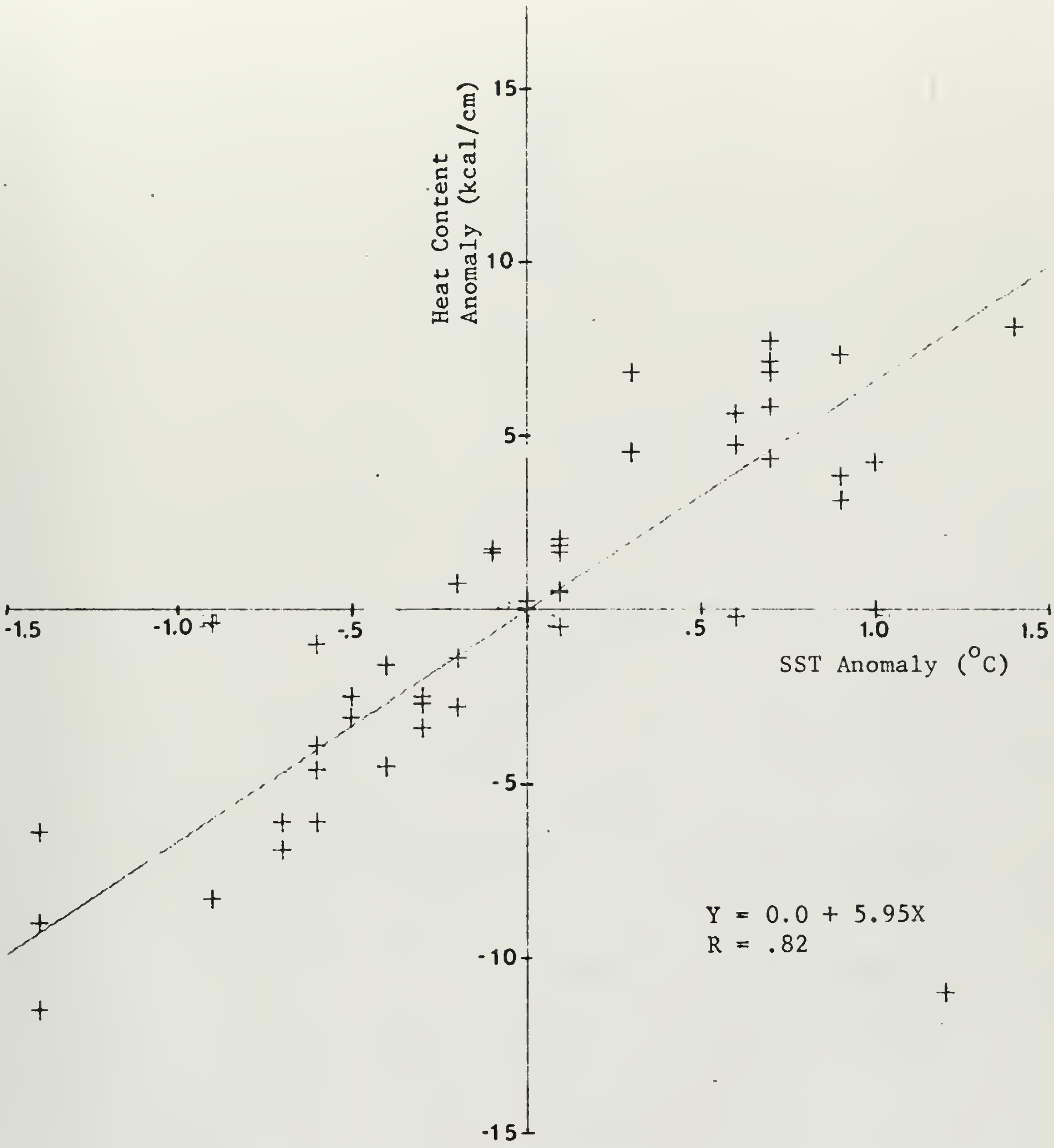


FIGURE 73. CORRELATION PLOT OF SST ANOMALY VERSUS HEAT CONTENT ANOMALY AT STATION N FROM 0-91M. (R=CORR. CORF.)

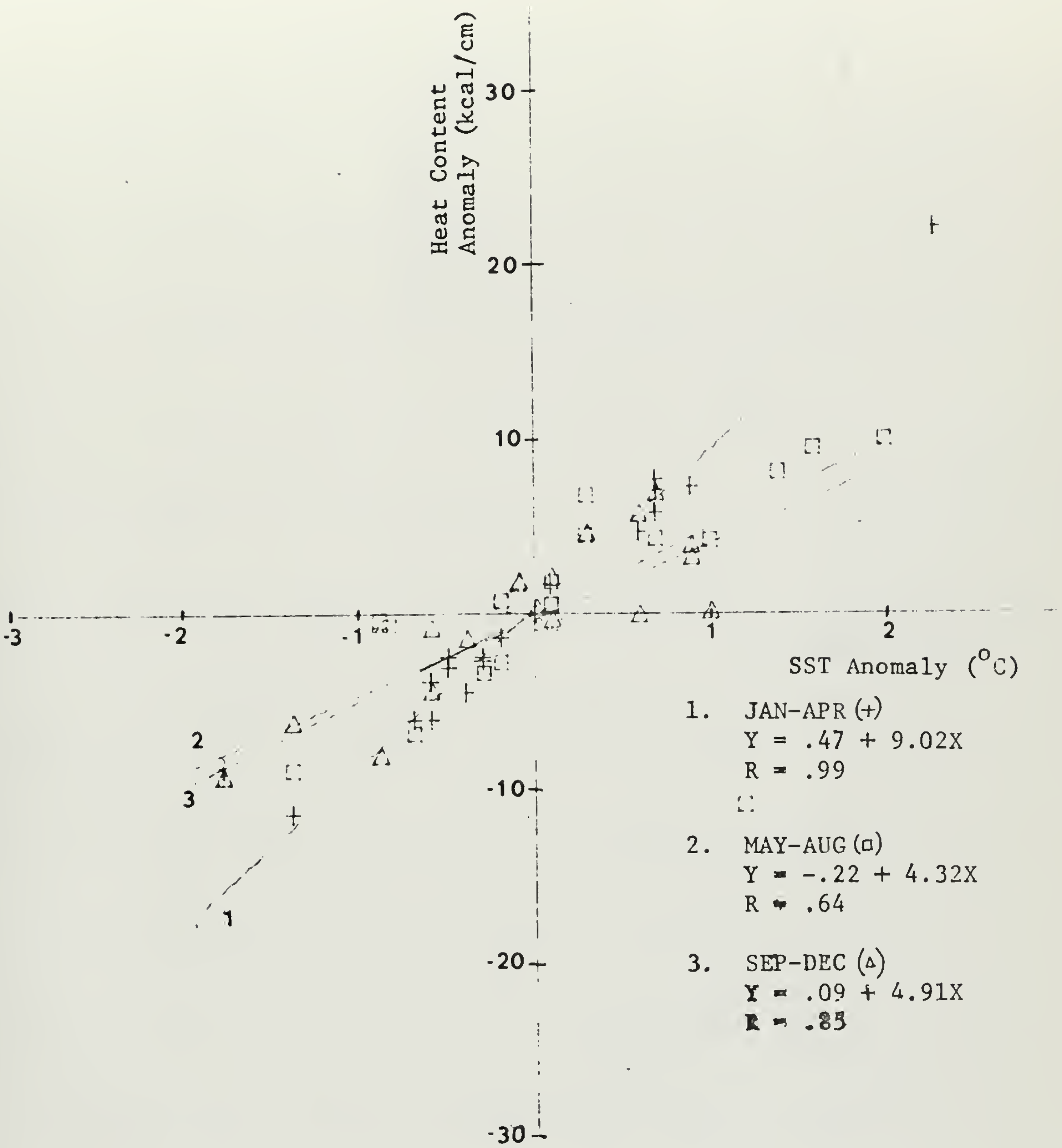


FIGURE 74. CORRELATION PLOT BY SEASON OF SST ANOMALY VERSUS HEAT CONTENT ANOMALY AT STATION N FROM 0-91M. (R=CORR. COEF.)

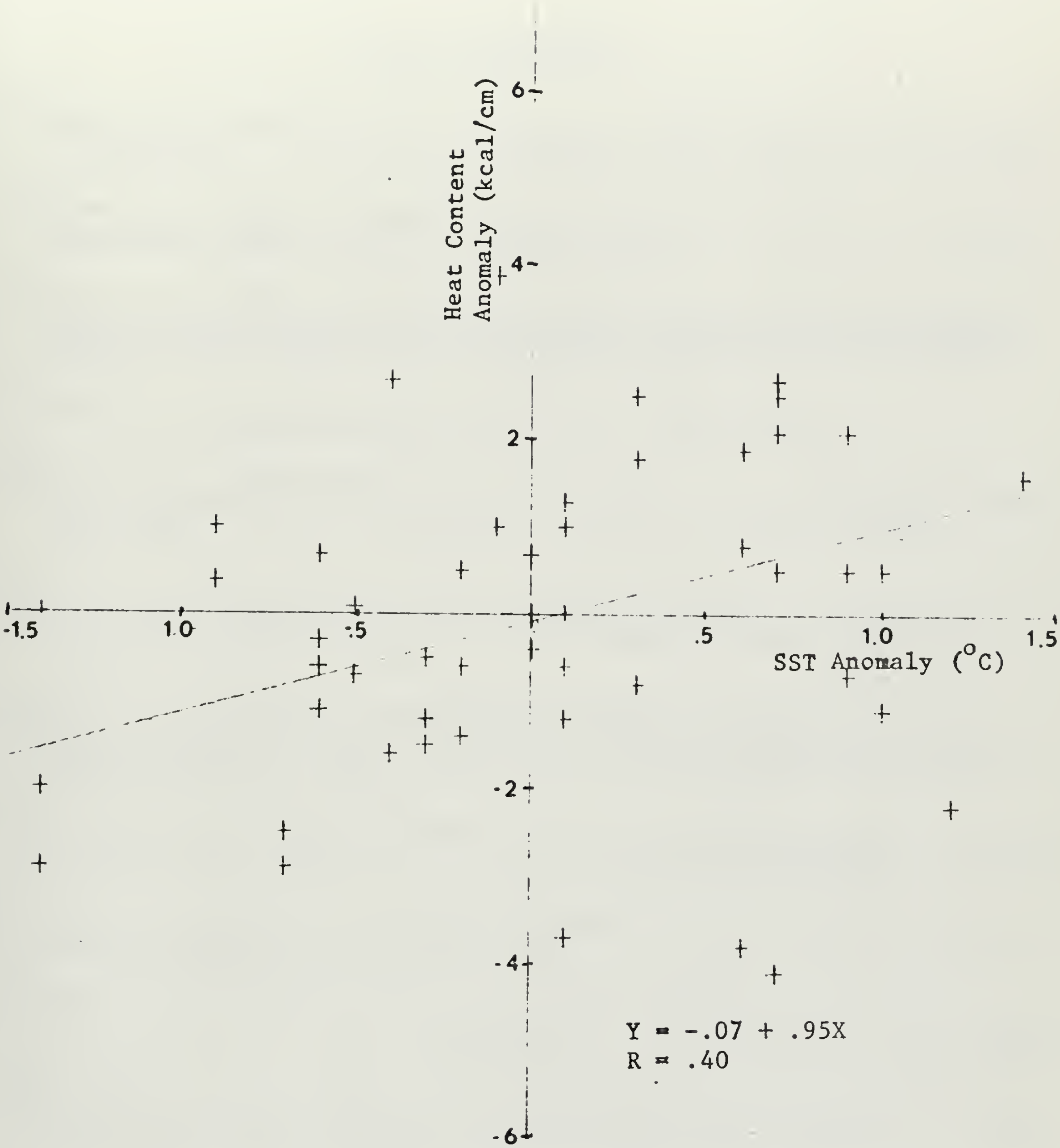


FIGURE 75. CORRELATION PLOT OF SST ANOMALY VERSUS HEAT CONTENT ANOMALY AT STATION N FROM 91-122M. (R=CORR. COEF.)

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13. ABSTRACT

Sea surface temperature (SST) anomalies from previous sources have been related to subsurface temperature anomalies obtained from BT's at six positions in the Northeast Pacific. In this manner some understanding of the value of SST anomalies as indicators of ocean energy states is achieved. Results show that for about 50% of the time, the SST anomaly generally extended to depths of 100 meters or more. November through April were found to be the months most favorable for the occurrence of these deeply penetrating anomalies. Summertime SST anomalies were determined to be shallow features of less than 40 meters and were not indicative of subsurface heat content. A close linear relationship was observed year round between SST anomalies and heat content anomalies in the top 30 meters of the ocean. There was little correlation between SST and heat content anomalies in the 91-122 meter layer.

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Subsurface Temperature Anomalies						
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